PROCEEDINGS OF A SYMPOSIUM ON THE SPRUCE BUDWORM

November 11-14, 1974 Alexandria, Virginia

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Proceedings of a Symposium on the Spruce Budworm

November 11–14, 1974
ALEXANDRIA, VIRGINIA

U.S. DEPARTMENT of AGRICULTURE
FOREST SERVICE
State and Private Forestry
Forest Insect and Disease Management

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FOREWORD

Although a point of contention, it has been said that the spruce budworm is the most important defoliator of forest trees in North America. During 1974 the spruce budworm and its resultant impacts were experienced throughout most of the spruce-fir forests of the United States and Canada. The current infestation is more severe in eastern Canada and Maine than elsewhere. The situation in Canada can best be summarized by a remark made by a Canadian scientist when asked of the budworm status. His reply was that, among other things, the Provinces of New Brunswick and Quebec contain "wall to wall" budworm. In an attempt to reduce anticipated heavy budworm populations and to protect millions of acres of highly vulnerable spruce-fir forest, large-scale aerial spray programs are planned for eastern Canada and Maine during 1975. In support of the opening argument, since 1949, when the first operational aerial control project was undertaken in Oregon, more area has been sprayed for spruce budworm control than for any other forest insect.

The purpose of the Symposium was to bring together those interested in spruce budworm management, to review the current situation in North America, and to consolidate and synthesize past, present, and future research efforts. These Proceedings, then, are essentially a compilation of this information. Contributors represent a diversity of occupations and interests: land managers, economists, entomologists, foresters, pathologists, chemists, and educators, to name a few. Agencies and organizations such as the U.S. Forest Service, Canadian Forestry Service, State forestry departments, private industry, and universities were also represented.

These Proceedings are divided into four panels:

I. The Spruce Budworm Problem in North America: The Current Situation and Outlook.

II. Objectives and Philosophies of Direct Control of the Spruce Budworm.

III. Control Methodologies Available or Planned for the Near Future.

IV. Environmental, Operational, and Economic Considerations in Suppression Programs.

Introductory remarks and the keynote address precede the first panel. Each of the four panels is then preceded by a synopsis. These summaries serve as an introduction, although during the Symposium they were not presented until the final day. They also provide continuity to the Proceedings and are particularly helpful to those who do not wish to pursue a particular subject in depth, or simply need to glean an overall concept.

Whether one is involved with the spruce budworm or not, by reading through the wealth of information herein, it is obvious that the spruce budworm is a problem not only of national importance, but of international concern as well. Explicitly then, it is a common problem shared by two Nations. In attempting to interrelate the highly diverse research efforts and findings, it is obvious in some cases that there is some duplication of effort. This, of course, can be expected with a problem of such magnitude, considering also the real facts of life such as regional emphasis (or de-emphasis), budworm population changes, sporadic funding, and most important, changes in priorities. In spite of these obstacles, inherent or otherwise, co-operation and overall co-ordination of effort between the research programs of both Nations are excellent and probably without precedent. It is hoped that the message contained in these Proceedings will further enhance this mutual understanding and co-operation.

William H. Klein

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INTRODUCTION

welcome and purpose

It is a pleasure and a privilege to extend a most cordial welcome to all of you at this Symposium.

Many of you have curtailed important work and traveled long distances to be here. It is good to see your interest and willingness to take the time to come here to consider and discuss some of the urgent problems and challenges involved in reducing losses caused by the spruce budworm to a tolerable level.

It isn't too often we have a work conference with the high-caliber people who are participating in this one. I would like to introduce all of you personally, but with this size group and time limitation, such is not practical. However, I am sure that we can all get acquainted through participation in the program, through discussion, and by visiting during the conference.

In developing the Symposium agenda, we conferred with a large number of people very concerned with the question of what we are going to do about infestations of spruce budworm. This collaboration indicated we should give emphasis to the following areas now scheduled for panel discussion:

RUSSELL K. SMITH
Director, Forest Insect and Disease Management, U. S. Forest Service, Washington, D. C.

Panel I - Definition of spruce budworm problem, its extent and intensity.

Panel II - Analysis of current control methods and strategy.

Panel III - Review of available technology and planned research and development.

Panel IV - Environmental, operational, and economic considerations involved in future suppression programs.

We believe that the panels set up for the Symposium will yield this information. There is a great deal of high-level competence, experience, and capability in this group; we encourage and urge all of you to participate fully in the conference. With your efforts, I am sure this meeting will be worthwhile and that your deliberations over the next 3 days will be a major contribution toward solving some of our urgent problems.

I would like to introduce Chief John McGuire, who will welcome us and get this Symposium underway. John, we are glad to have you here.

forest environmental protection: challenges in insect and disease management

The management of our forest resources, the utilization of the products they supply, the many uses they receive, and the effects these actions have on the forest environment are becoming a greater public concern each week.

Because of this increasing attention and emphasis on environmental impacts, we must often re-evaluate our approach to problems. We are being forced to recognize that in many instances the traditional approach—the old way of doing things—is an era that has passed. We have to develop new and innovative approaches to solve these problems.

There are many examples of these new approaches being undertaken by Federal, State, and private agencies. The use of tubules for tree seedlings, applications of remote sensing in forestry, and use of biological control methods against insect pests are some. However, I believe one of the best examples is our participation in this Spruce Budworm Symposium. This session can be considered innovative from several aspects. We are bringing together an international group to determine the current status of the spruce budworm problem. By using the most up-to-date information we can determine, through group discussion and evaluation, our needs and future course

JOHN R. McGUIRE
Chief, U. S. Forest Service, Washington, D. C.

of action. We have here not only scientists from various disciplines, but also resource managers from both the United States and Canada, representing Federal, Provincial, and State agencies, as well as private industry.

I wish to take a moment to welcome each one of you to this session. I am confident that through our co-ordinated efforts and co-operation, good progress will be made in developing solutions to the spruce budworm problem. Many of the obstacles that now seem insurmountable will begin to fall by the wayside as we utilize the expertise of this group and move ahead in a combined effort.

This period in history is critical. We are facing increasing inflation, an energy crisis, and international stresses. Yet, perhaps surprisingly, 1974 has been a year of major accomplishments in forestry legislation and other related areas. There is an atmosphere of seeking new initiatives by the national Administration, in the Congress, in the industry, and by people themselves. We must look ahead for an effective way of meeting the problems and needs of today and tomorrow.

It is clear that there is a need to accelerate research and development, leading to new and better ways to manage forest insects and diseases. Many people and organizations are involved and concerned. In the "old days" each research and action group would go its own way, with little co-ordination. As a result, our knowledge contained gaps; and duplication of studies was often undertaken. But the United States Department of Agriculture has established an innovative approach that seems to have real promise. A staff officer and three "program managers" plus supporting staffs have been set up to develop an all-out research and development program on gypsy moth, Douglas-fir tussock moth, and southern pine beetle. The Forest Service, the Animal and Plant Health Inspection Service, the Cooperative State Research Service, and several State universities are directly involved. The Office of Management and Budget agreed that accelerated programs, developed on a priority basis, are a sound organizational approach. Consequently, some $6 million was added to the President's FY 1975 budget and has now been appropriated to start these 3- to 5-year efforts.

Spruce budworm was not included as part of the accelerated programs because, at the time of the evaluation, the infestation had not built up to present high levels. However, based on recent information and a new look at the current infestation of approximately 80-90 million acres in Canada and the United States, the critical nature of the problem has become evident. We must combine our capabilities and resources, and develop the motivating force needed to obtain the answer the land manager needs to reduce and, if possible, avoid catastrophic losses in the future.

Countrywide a number of forest pests, including the gypsy moth, Douglas-fir tussock moth, southern pine beetle, mountain pine beetle, dwarf mistletoe, root rots, and several of the tree rusts, as well as spruce budworm, are causing severe losses in both mortality and growth increment. The total impact to the forest resources in every geographic area of the Country has been at record levels for several years.

Today we have better tools and strategies to employ against destructive outbreaks than we have had at any other time in the past. Yet, the current losses show there are many things still to be learned about managing forest pests before insect and disease losses can be readily kept within tolerable limits.

The public's attention and interest have been aroused regarding these insect and disease problems. Some of this interest has been voiced in the form of public discontent over the adverse impacts of insect and disease suppression projects. Some believe these projects may have seriously impaired the quality of the Country's forests. Many have expressed concern over the unnecessary volume of the Nation's timber—already in short supply—that is being destroyed outright or is sustaining severe growth losses that could further reduce our social and economic growth. We believe that the net effect of the public's new interest has been beneficial. Public support will eventually assist us in more quickly reaching a higher level of proficiency in forest pest management and environmental quality protection.

The solutions to our problems are becoming more difficult to achieve and will continue to become increasingly complex because of environmental considerations; but this is only proper. We must be responsive to the environmental impacts associated with our programs and the programs of others. We must broaden our responsibilities to include all aspects of environmental quality as it affects the health and vitality of forest stands.

All of this points up the need for more reliable information on the impact of various insects and diseases on forest resources. This information will enable the land manager to use the available manpower and dollars more effectively and efficiently.

We are placing much greater emphasis on evaluating the performance of ongoing and past programs and projects to enable us to better establish future priorities and courses of action. This effort requires the collection, storage, and manipulation of detailed program data and technical information. We must begin to integrate our insect and disease survey and evaluation information with data from all forest resources to determine total impact. In the past, we have often worked on the premise that all insect and disease outbreaks are detrimental and must be controlled. Perhaps in most instances this has been true, but the effect of the outbreak on wildlife and aesthetic resources may have been a positive factor that needs more recognition.

We are working toward the improvement of our survey and monitoring designs. Through the use of the most up-to-date methodology and techniques, we hope to cut the time required for our detection and evaluation surveys in half and to supply survey results to land managers at an earlier date. The data produced will be more reliable and acceptable in making management decisions. We can then better determine the need and justification for the use of funds necessary for insect and disease suppression projects.

As many of you know, the competition for dollars in overall forest management and protection programs has become keen. This problem is compounded by the recent efforts to reduce Federal spending at the very time when the cost of doing business has increased sharply due to inflationary factors and new environmental considerations.

A justification for Federal funds must now be very carefully considered and prepared. The President's Office of Management and Budget is not particularly impressed by the general statement that millions of acres of trees are infested by insects and that a large volume of timber is dying. Nor is it impressed that many livelihoods are tied directly to the forest resource or with similar arguments. What does impress the Office are the specific benefits that can be derived from the expenditure of alternative amounts of Federal dollars. In other words, the benefit-cost evaluation is directly associated with the proposed project. We must never forget that every dollar appropriated for forest insect and disease protection is one less dollar available for medical research, mass transit, flood relief assistance, or similar needs.

At the moment, our benefit-cost evaluations need improvement. These evaluations and all associated data must be finely honed. We must be in a position to point out what effects are specifically associated with forest pests or pollutants when no corrective action is taken. And we must be able to quantify the benefits that will accrue to the American people under alternative levels of spending for forest pest management and environmental quality evaluation activities. When we have good information, we can make good decisions; otherwise, we are forced to do the best possible job with what we have.

Entomologists and pathologists have pointed out on many occasions that our most urgent need is to systematically determine the extent of losses from forest insects and diseases we must absorb each year. This urgency for action has gone mostly unheeded. The variability of available figures on losses is unknown and time intervals over which they have occurred are not indicated. The value of general estimates for analytical purposes is small. We need reliable comprehensive data of forest insect and disease losses that will stand up to close scrutiny. The data must define the impact on all forest resources. If this information were now available, we could evaluate our losses more realistically and use funds and manpower more efficiently to implement those measures needed to reduce the losses.

Even though we do not have all the information available on impacts, we must often continue our suppression programs. It is the policy of the Department of Agriculture to practice and encourage the use of those means of effective pest control which provide the least potential hazard to man, his animals, wildlife, and other components of the natural environment. No single method of pest control will always be effective. We must have and use a variety of suppression techniques, selecting the proper method or combination of methods for each situation.

Our activities have often involved an integrated control approach that employs a combination of methods to suppress a pest population. It involves maximum reliance on natural controls along with various methods of direct suppression. When these integrated systems are used in conjunction with good silvicultural practices, the result is a viable integrated suppression project at work. This enables us to attain our objective of more efficient pest control with minimum adverse effects at an economical cost.

We need to increase our capabilities in monitoring any insect or disease control effort to give us a better understanding of the trade-offs we make when we use pesticides. What is the impact on the environment, including water, wildlife, and soil? What effect will these trade-offs have on economic and social conditions in the area? These are the questions we are asked and have to answer.

Under our current concepts of insect and disease control, we continue to sustain rather severe losses before taking a suppression action. This delay affects our management planning and ultimately will affect the amount of timber available in future years. We must examine our current policies carefully. It may be necessary to undertake our control effort during an early stage of a specific outbreak. This may mean a stepped-up suppression effort, but in the long run, the cost of this type of operation could reduce our losses. The gain we achieve in resources saved could be substantial. However, we don't have all the answers to suppression tactics, and perhaps we will be able to develop more realistic strategy as a result of your Symposium this week.

Regardless of how we proceed, we need new methods and techniques for accomplishing the suppression job. Pesticides that are effective, yet environmentally safe, must be developed for future use. As these materials are developed and tested by the chemical companies, we will need to determine, through field tests and pilot projects, the feasibility of using these pesticides on different forest insects and diseases.

This is a big job. It involves determining not only the proper pesticide to use, but also the method of application. It involves more proficient use of these pesticides through training and certifying those people involved in the suppression efforts. We have developed many new methods and techniques that have been useful in control application, but with our changing world and concern for the environment, we still have a long tough job ahead of us.

The future for forest insect and disease management looks bright. But the challenges ahead will require a dedicated and committed group of people to attain the objectives needed for a good management effort. By taking advantage of the available expertise, we can identify our needs and develop a sound course of action. Through this co-operative effort progress will be made. I am confident you can do the job.

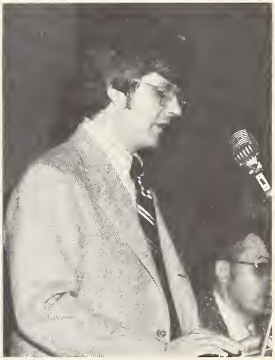
I

The Spruce Budworm Problem in North America– The Current Situation and Outlook

The objective of this Symposium is to examine and analyze the spruce budworm problem, and to formulate recommendations for action programs. But, before we can do this, we must first be aware of the present status of spruce budworm populations and the course they are likely to follow in the future.

This panel was structured to present a brief picture of local budworm situations and the problems the defoliator is causing throughout Canada and the United States; specifically:

1. The locations and acreages involved in current outbreaks.
2. The species of budworm and the hosts that are involved.
3. The relative levels of defoliation which occurred this past season.
4. Estimates of the actual damage resulting to date, particularly the consequences of that damage as it affects individual trees and the forest resource as a whole.



MODERATOR CHARLES F. KREBS
Assistant Director, Forest Insect and Disease Management, U.S. Forest Service, Washington, D.C.

5. The probable nature of spruce budworm populations next year, with the notation of any new areas where outbreaks might be expected.

As you remember, our panelists began with a summary of the spruce budworm situation in the West, reporting on conditions in the Pacific Northwest and California, followed by the Rocky Mountain States, Western Canada, and Ontario. From there we moved south into the Lake States, then on into the Province of Quebec and the northeastern United States, and concluded with a report of the budworm situation in the Maritime Provinces.

I am not going to repeat the many statistics presented by our panelists; *that* information will be contained in the proceedings. Instead I would like to make a few remarks summarizing the general situation as our panelists viewed it.

Several species of budworm other than the spruce budworm, *Choristoneura fumiferana* (Clemens), and the western spruce budworm, *C. occidentalis* Freeman, were identified as causing localized damage. They were *C. viridis* Free., *C. lambertiana* (Busck), *C. orae* Free., *C. biennis* Free., *C. conflictana* (Walker), and *C. pinus* Free.

C. viridis, sometimes called the "green form budworm" or Modoc budworm, has infested some 233,000 acres of white fir type in California and Oregon. Preliminary indications are that populations are on the decline.

C. lambertiana, usually called the sugar pine tortrix, has infested close to 18,000 acres of lodgepole, western white, and white bark pine in areas adjacent to the Modoc budworm infestation. Populations are expected to continue at the same level.

C. orae is causing some localized damage to sitka spruce and amabilis fir in western Canada. Current populations are generally light.

C. biennis, the 2-year form, has recently increased in numbers and has infested approximately 100,000 acres of white spruce and alpine fir. Because damage occurs in alternate years, this insect is generally not much of a problem.

C. conflictana, the large aspen tortrix, has caused serious defoliation in Lake States aspen, but populations are much lighter this year and no mortality has been observed.

C. pinus, the jack-pine budworm, has been observed in Minnesota, Wisconsin, Michigan, and New York. Approximately

313,000 acres were infested in the three Lake States and populations are expected to continue at about the same level next year. No significant problems are occurring in New York.

Populations have risen in the two principal species of budworm, *C. occidentalis* and *C. fumiferana*. Approximately 5,215,000 acres of fir are currently infested by *C. occidentalis* in the western United States; an additional 282,000 acres are infested in British Columbia and the insect is increasing. Mortality is expected in Douglas-fir stands in the Province this year since the infestation has been continuing for several years. Western spruce budworm populations are expected to remain at current levels in Oregon and Washington. Insect populations are on the decline in areas of older defoliation in Idaho, Montana, and Wyoming, but an explosive buildup is beginning to occur in a number of recently infested stands in those States.

C. fumiferana has infested 30,000 acres of white spruce in British Columbia, but populations are declining. Some 344,000 acres of spruce and fir are moderately to severely damaged in the Lake States and entomologists there believe that conditions are conducive for an increase. In Ontario, Quebec, the Maritime Provinces, and Maine the spruce budworm has infested 124 million acres. Populations in this area are much greater than in any previous year, and the outlook is not good.

Since few meaningful recommendations could be formulated from the status summaries presented by this panel, we focused our attention on some aspects of conducting spruce budworm surveys and evaluation, including the reporting of infestation statistics. We were particularly interested in the similarity of techniques employed and, hence, whether the data reported by the various agencies and/or units are comparable. During the remainder of this summary, I would like to briefly mention several of the points we discussed.

We found that the same general criteria are used by the various units in reporting spruce budworm infestation statistics in Canada and the United States. Aerial surveys are utilized to determine infestation boundaries and defoliation intensities. The defoliation intensity classes recognized are similar to those presented by Graham: light—less than one-third of the tree crown damaged; moderate—one-third to two-thirds of the tree crown damaged; and heavy—over two-thirds of the tree crown damaged. Accuracy of the aerial survey data, of course, is predicated by the skill of aerial observers and photo interpreters, although ground truth is also collected in an effort to minimize errors.

Most of the panel members are reasonably satisfied with existing methods for detecting and classifying infested stands and for measuring stand damage, particularly in light of present fiscal and manpower constraints. While it is conceded there is always room for improvement, such an effort may not be a viable pursuit unless managers are prepared to allocate additional manpower and funds for surveys.

Some of the western entomologists expressed a little uneasiness with the current procedures used for evaluating populations. This probably results from the fact that the Westerners have not had any budworm populations to work with until just recently, and consequently their objectives might not be as readily defined. One should keep in mind that population evaluation and prediction are somewhat easier when the budworm is at either relatively low or relatively high levels, but that they are quite difficult when population levels fall in between.

Tree climbing is used as part of current egg-mass sampling procedures in the West, but it is not employed in the East. Western entomologists would like to see a refinement in these procedures so that climbing would no longer be necessary.

Western entomologists indicated another area needing improvement is the separation of new egg masses from old. Other panelists pointed out that winter foliage surveys, often employed in the East, are most helpful in evaluating budworm population numbers and might be used in the West to avoid the egg-mass aging problem.

While the panel members feel they are quite capable in classifying stands as well as in estimating budworm damage and mortality, all agreed that better methods are needed for measuring the damage occurring to other resources. There is also some question on interpreting spruce budworm damage statistics (i.e., what are the damage figures telling us?), although the members' opinions vary on how strongly they feel about this point.

It is generally accepted that budworm-caused tree mortality occurs in the western states after 4 to 5 years of successive defoliation, whereas mortality can occur after the second year of defoliation in Maine and southern New Brunswick because of stand conditions there.

Better definitions are needed relative to economic loss levels. These levels must be expressed in terms of the amount of loss a given land manager can afford to lose. The solution to this will require a close working relationship between land managers, forest pest managers, and economists. We cannot over-stress the importance of Forest Pest Management personnel having constant interaction with land managers to "sharpen up" objectives.

Thus far we have discussed current methodology as it is applied on a year-to-year basis. Suitable techniques are not available for long-term prediction of budworm populations, although such techniques are urgently needed if we are to effectively get on top of the budworm problem.

When reviewing this panel's papers, please keep in mind that while the total budworm-infested acreage is currently much lower in the West in comparison to the East, the figures may be misleading. The current spruce budworm situation in the West may be equally as important as in the East, or more so; each infestation must be evaluated on its own attributes. Benefit-cost analyses play a very important role here.

In conclusion, we would like to make the plea that we are talking about a long-term undertaking in order to find solutions for the spruce budworm problem. Let's make sure that the ball is not dropped and the problem not forgotten once current populations are suppressed.

1

the spruce budworm problem in washington - oregon - california

DAVID A. GRAHAM
Director, Forest Insect and Disease Management, Pacific Northwest Region, U. S. Forest Service, Portland, Oregon

In 1974 two species of budworm were in epidemic status on 782,330 acres in Washington, Oregon, and California: the western spruce budworm, *Choristoneura occidentalis* Freeman, and the Modoc budworm, *C. viridis* Free.

Western spruce budworm damage occurred on 549,660 acres of Douglas-fir, *Pseudotsuga menziesii,* and grand fir, *Abies grandis,* in Washington and Oregon. Modoc budworm larvae, feeding only on white fir, *A. concolor,* defoliated 232,605 acres in Oregon and California.

Western Spruce Budworm

Most of the 549,660 acres of western spruce budworm activity are located in the State of Washington on the east slope of the Cascade Mountains, in the area between the town of Cle Elum and the United States-Canada boundary (Table 1). The outbreak encompasses the Okanogan and Wenatchee National Forests and the North Cascades National Park. About 15 percent of the area affected is in State and private ownership.

Most of the 1974 spruce budworm damage in Washington was classified as "light." "Heavy" defoliation occurred on

Table 1. Summary of western spruce budworm, *C. occidentalis* Free., epidemic infestations in Oregon and Washington, 1974

Location	Defoliation (acres)			
	Light	Moderate	Heavy	Total
Oregon				
Wallowa-Whitman area	1,980	—	—	1,980
Warm Springs I R	6,920	—	280	7,200
Subtotal	8,900	—	280	9,180
Washington				
Okanogan area	156,340	17,200	2,600	176,140
Wenatchee area	302,270	35,130	3,040	340,440
North Cascades N. P.	18,220	5,200	480	23,900
Subtotal	476,830	57,530	6,120	540,480
Total	485,730	57,530	6,400	549,660

slightly over 6,000 acres.[1] Some of the infested area has been defoliated for 3 years, while a few scattered patches have been defoliated for 4 years.

Almost all the spruce budworm damage is in old-growth stands. Some height and radial growth loss is occurring in scattered patches on about 30,000 acres in the Wenatchee area and 40,000 acres in the Okanogan area. Top kill and tree kill are taking place in a few areas. It appears that the outbreak has caused very little recreational impact, while the additional fire hazard has not yet been assessed.

Western spruce budworm activity in Oregon during 1974 was limited. A total of 9,180 acres was defoliated, most of this on the Warm Springs Indian Reservation. The remaining 1,980 defoliated acres are in the Wallowa-Whitman area adjacent to the Snake River Canyon. Little or no top kill or tree kill has been observed in either of these outbreak areas in Oregon. The infestation on the Warm Springs Indian Reservation is only 1 year old, while the outbreak in the Wallowa-Whitman area is 2 years old.

Modoc Budworm

Populations of the Modoc budworm caused visible defoliation on 232,605 acres of white fir type in the Modoc National Forest in California and in the Fremont National Forest in

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[1] Definitions of current-year infestation severity classes are: light, less than 1/3 of the tree crown damaged; moderate, 1/3-2/3 of the tree crown damaged; heavy, over 2/3 of the tree crown damaged

Oregon (Table 2). Most of the damage occurred in California with a total of 143,035 acres defoliated; 89,570 acres were defoliated in Oregon. This outbreak almost covers the North and South Warner Mountain Range. The infestation also includes an area surrounding Manzanita Mountain, southwest of Alturas, California, with a smaller infestation in the Gearhart Mountain Wilderness Area, northwest of Lakeview, Oregon.

Table 2. Summary of modoc budworm, *C. viridis* Free., epidemic infestations in Oregon and California, 1974

Location	Defoliation (acres)			
	Light	Moderate	Heavy	Total
Oregon				
Fremont area	72,040	12,370	5,160	89,570
California				
Modoc area	53,295	70,520	19,220	143,035
Total	125,335	82,890	24,380	232,605

Modoc budworm damage is still being examined. Most of the outbreak area has been seriously defoliated during the past few years. Some height and radial growth loss is evident on 206,000 acres and top killing and scattered tree mortality have occurred on some 42,000 acres within the total outbreak area.

The damage is primarily in old-growth white fir stands, and to a lesser extent, in residual stands left by tree selection logging. Very little recreation impact has occurred and the fire hazard has yet to be assessed.

Western Spruce Budworm Outlook for 1975

Preliminary results of 1974 ground surveys indicate the western spruce budworm populations will remain at high levels in the Wenatchee-Okanogan areas in Washington. Direct control may be required in 1976 if the outbreak does not collapse in 1975. In Oregon moderate increases are expected in the budworm population on the Warm Springs Indian Reservation, with slight increases anticipated in the Wallowa-Whitman area.

Modoc Budworm Outlook for 1975

Preliminary results from the 1974 survey indicate a sharp decline in budworm populations in the older outbreak areas in Oregon and California.

In California the outbreak probably reached its greatest extent in 1974, judging from the host and elevational distribution of the 1973-74 infestation. Although there is a possibility of an outbreak developing elsewhere in northern California, none is expected.

In Oregon the Modoc budworm outbreak is expected to decline in parts of the North Warners where defoliation has occurred for the past 2 years. Some defoliation is expected to occur elsewhere in the North Warners and some new infestation centers may develop in white fir stands located north and west of the Gearhart Mountain Wilderness Area. However, very little serious damage is expected, based on the history of past budworm infestations in this area.

Another Budworm

The sugar pine tortrix, *C. lambertiana* (Busck), caused serious defoliation to several different species of pine in California and Oregon during 1973 and 1974. Populations of this pest were detected in and adjacent to the Modoc budworm outbreak area. Instead of feeding on white fir, larvae defoliated lodgepole pine, *Pinus contorta*; western white pine, *P. monticola*; and whitebark pine, *P. albicaulis*. A total of 17,000 acres of these pines was defoliated in California; in Oregon, only 760 acres were defoliated.

An evaluation of the sugar pine tortrix infestation is being conducted in California. Some top kill and growth loss have been observed, with most damage occurring in mature and overmature stands.

Populations of the sugar pine tortrix are expected to continue at present levels for at least 1 more year.

2

the western spruce budworm problem in the northern, central, and southern rocky mountains in 1974

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Western spruce budworm defoliation was detected on 4,663,185 acres in the Rocky Mountain area in 1974. This is an increase of 763,225 acres over 1973.

The extent of detectable budworm defoliation in 1973 and 1974 follows:

U. S. Forest Service Region	*Area*	*Acres defoliated*	
		(1973)	*(1974)*
1	Montana and northern Idaho	3,565,860	4,180,385
2	Colorado	95.000	125,000
3	New Mexico	15,000	0
4	Southern Idaho, western Wyoming, Utah	224,100	357,800
	Total	3,899,960	4,663,185

Region 1 (Montana and Northern Idaho)

Some infestations have intensified and expanded; some have remained static; and others have declined in intensity and/or extent in 1974. Region 1 budworm activity mushroomed from 166,530 acres in 1973 to 689,252 acres in 1974 in the national forests east of the Continental Divide in Montana. These are the same forests that suffered heavy budworm damage in the 1950's and early 1960's.

The massive infestations on the Nezperce and Clearwater National Forests declined in intensity and acreage in 1974. Part of this decline has been attributed to depletion of host type. A damage survey on the Nezperce National Forest showed 138,692 acres sustained permanent injury (top kill or tree mortality) due to budworm feeding. One drainage had over 50 percent of the volume killed or with dead tops. A budworm impact survey on the Clearwater National Forest showed that in addition to top kill and tree mortality, there was a reduction in the radial growth rate of over 27 percent on host trees compared to a 1.8 percent reduction on adjacent nonhost trees.

The fall 1974 egg-mass survey indicated high egg counts (approximately 20 egg masses per 1,000 square inches of foliage) in "east-side" forests. It is predicted that the outbreak will increase east of the divide and continue to decline west of the divide except on the Idaho Panhandle national forests and other localized areas.

Region 2 (Colorado)

The budworm impact in Region 2 is primarily associated with home, recreation, and Christmas-tree growing sites. Localized areas of visible budworm defoliation were located as far north as Rocky Mountain National Park and in the south almost to the New Mexico border. Defoliated areas were relatively small, averaging less than 5,000 acres in size. All defoliation was classed as light to moderate in 1974. Budworm activity has slowly built up over the past 5 to 7 years. The trend for 1975 is predicted to be static to slightly increasing in all areas.

Region 3 (New Mexico)

There was no budworm defoliation observed during the 1974 aerial detection surveys in Region 3. On-the-ground examination and systematic evaluation surveys revealed localized areas of budworm injury. Egg-mass surveys indicate only light defoliation can be expected in these areas in 1975.

Region 4 (Southern Idaho, Western Wyoming, and Utah)

There are two major areas of budworm injury in Region 4: Over 338,000 acres are infested in southern Idaho on the Boise, Payette, Salmon, and Targhee National Forests; about 19,000 acres of visible defoliation exist on the Teton and Bridger National Forests in western Wyoming. Four hundred acres of defoliation were also detected on the Ashley National Forest in northeastern Utah.

Ground cruises using the variable plot method were undertaken from 1971 to 1973 in heavy outbreak areas to measure the impact of budworm on timber. In the 17 areas surveyed tree mortality ranged from 0 to 25.2 percent of the host type; most mortality was restricted to small, suppressed understory trees. Top kill ranged from 3.5 percent to 55.6 percent of the host type. In most areas radial growth decreased during the infestation period and increased following cessation of feeding.

It is expected that budworm infestation levels will remain about the same or decrease slightly on the Payette National Forest in 1975. Data have not been analyzed to predict a 1975 trend in other infested areas.

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spruce budworm, choristoneura fumiferana (clemens), in ontario and the prairie provinces

Ontario

J. R. Blais (1968) presented a summary of the history of budworm outbreaks in eastern Canada (including Ontario), determined from growth ring analyisis of old spruce trees. Outbreaks in Ontario could be traced back to 1702; however, no predictable cycle could be detected, although it was evident that the periodicity of outbreaks is longer in Ontario than further east. A cartographic history spanning 1909 to 1966 was complied by C. E. Brown (1970). The last major outbreak in Ontario prior to the present one began in the 1930's, and by the late 1940's it covered virtually all of Ontario. After extensive small-scale tests in Algonquin Park in 1944, approximately 100 square miles (64,000 acres) were sprayed in northwestern Ontario in 1945 using 1 pound DDT per acre. Although damage was retarded, only 50-60 percent of the larvae were killed. Further tests were conducted in 1946 when it was shown that 2 pounds DDT per acre gave 90-percent kill. All these trials were notable for the great care taken to assess the environmental impact (Johnston, 1949). Apart from a small-scale operation in the late 1920's using calcium arsenate, this was the only use of insecticides against the spruce budworm in Ontario prior to the present out-

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break. Consequently the 1940 outbreak was allowed to run its course and it collapsed in the early 1950's over much of the Province, but persisted in northwestern Ontario into the early 1960's. In part of the outbreak centered on Lake Nipigon 17 million cords were killed, approximately 60 percent of the host trees (Elliott, 1960).

The current outbreak in Ontario was first detected in 1967. Since then the course of the outbreak has differed in different parts of the Province. This is summarized in Table 1, together with the extent of operational aerial spraying to date.

Table 1. Areas of heavy defoliation, control, and damage, Ontario, 1966-74

Year	Southeastern				Northeastern				Northwestern			
	Area (1,000 acres)		Insecticide[1]	Damage[2]	Area (1,000 acres)		Insecticide[1]	Damage[2]	Area (1,000 acres)		Insecticide[1]	Damage[2]
	Defol.	Sprayed			Defol.	Sprayed			Defol.	Sprayed		
1966	0				0				0			
1967	150				8				40			
1968	300				500				0	275	Phos. Fen.	
1969	768				1,650				40	26	Fen.	
1970	1,600	1.25	Fen		5,200	11	Fen.		130	11	Fen.	
1971	4,500	0.4	Fen.	M	8,600	8.6	Fen.	T	130	72	Fen.	
1972	5,800	2.0	Fen.	M	13,400	9.6	Zec.	T	70	37	Zec.	
1973	6,000	5.75	Fen.	M	12,500	11.0	Zec.	TM	10	77.3	Zec.	
1974	5,500	2.0	Zec.	M	18,500	26.0	Zec.[1]	TM	11.5	21.0	Zec.	

[1] Fen. = fenitrothion; Phos. = phosphamidon; Zec. = Zectran.

[2] T = top kill; M = mortality.

In the northeast and southeast the policy adopted by the Ontario Ministry of Natural Resources has been to allow the outbreak to run its course, protecting only those areas of high recreational or high timber value. Since the wood-using industries of Ontario are not as dependent upon white spruce and balsam fir as are the more eastern Provinces, there has been little need to protect timber values, and most of the protection has been in provincial parks. In the northwest recurrent hot spots, which may be relicts from the previous outbreak or extensions of an outbreak in Minnesota, have been threatening large areas of spruce-fir to the north. Consequently a policy designed to prevent the spread of these outbreaks has been adopted which so far appears successful.

The situation at the end of 1974 was as follows. In southeastern Ontario the area of defoliation and the population densities were down slightly from 1973. This area is contiguous with an extensive outbreak in Quebec in which trees are dying over 2 million acres. Possibly the outbreak in southeast Ontario has lost its impetus and is now on the decline; 1975 will be a critical year.

In the northeast populations have fully recovered from a minor setback due to late frost in 1972; populations for 1975 are expected to reach a record high, with further extension of the outbreak.

The situation in the northwest remains apparently under control. Continued vigilance and prompt action hopefully will prevent a widespread outbreak in this area.

Prairie Provinces

The spruce budworm, *Choristoneura fumiferana* (Clemens), occurs throughout the range of its hosts, white spruce, red spruce, and balsam fir. West of the Manitoba-Ontario border, its range extends into central and northern Manitoba, northern Saskatchewan, northern Alberta, the extreme northeastern corner of British Columbia, the river valleys of the Yukon and Northwest Territories, and in outlying areas where its hosts occur, such as the Cypress Hills in Saskatchewan, and in North Dakota. The vulnerability of the forest to damage by *C. fumiferana* appears to increase as the number of balsam fir increases. Therefore, west of the Manitoba border, where balsam fir content is generally low, the budworm is of little economic importance. Outbreaks occur sporadically on white spruce throughout its range west of this line, but white spruce has the ability to withstand prolonged defoliation, and some outbreaks along northern river flats have persisted for 25 years. Mortality has generally occurred in areas beyond the present harvesting limits. As yet, apart from a spray operation in the Spruce Woods Recreational Area in Manitoba using fenitrothion in 1974, there has been no control. However, as these northern stands come within range of harvesting and as balsam fir content increases—which appears to be an inevitable effect of harvesting—it is probable that the budworm will become a more serious problem in these areas.

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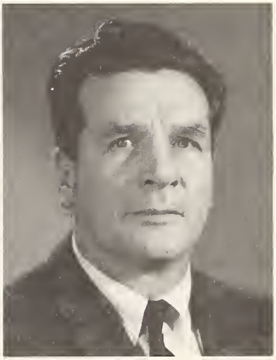
spruce budworms, choristoneura spp., in british columbia, 1974



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presented by CHRIS J. SANDERS

The first recorded outbreak of spruce budworm in British Columbia was on the south end of Vancouver Island in 1909. Since then infestations have occurred frequently in various parts of the Province.

In recent years spruce budworm has been separated into a group of species, four of which are capable of causing damage in British Columbia: *Choristoneura occidentalis* Freeman, which has currently reached outbreak proportions in Douglas-fir stands in southwestern British Columbia; *C. fumiferana* (Clemens), in the northeastern part of the Province where an infestation has persisted in white spruce stands for a number of years; *C. biennis* Free., which has been relatively quiet since 1964 but increased on white spruce in the central interior of the Province in 1974; and *C. orae* Free., which occurs occasionally in Sitka spruce–amabilis fir stands along the north coast.

C. occidentalis Free.

Recent infestations of *C. occidentalis* recurred in more or less the same areas as the epidemics of 1943-48 and 1953-58. The current outbreak, which began in 1969, covers more than

280,000 acres. Heavy Douglas-fir defoliation has occurred on more than 13,000 acres.

Table 1 shows the extent of *C. occidentalis* infestations in Douglas-fir stands since the outbreak began in 1969 in southwestern British Columbia together with a summary of the results of annual egg-mass evaluation surveys.

Table 1. Extent of *C. occidentalis* Free. infestations in Douglas-fir since 1969 in southwestern British Columbia and results of egg-mass evaluation surveys

Year	Defoliation (acres)			Range in average number of egg masses per 100 square feet at sample plots
	Light-moderate	Heavy	Total	
1969	400	0	400	–
1970	15,840	835	16,675	24 - 742
1971	36,515	2,775	39,290	31 - 297
1972	98,100	1,860	99,960	69 - 364
1973	158,920	22,020	180,940	30 - 159
1974	267,940	13,400	281,340	50 - 185

No tree mortality has been recorded to date in heavily defoliated stands but at one location 2 percent of the trees were completely defoliated and designated as possibly dead; 38 percent had the upper crown completely defoliated with heavy defoliation of the lower crown; 46 percent had the upper quarter completely defoliated with moderate defoliation of the lower crown. While some tree mortality will no doubt occur, further defoliation is expected in 1975 and will increase the possibility of extensive tree mortality. A recognizable but unmeasured loss is the reduction in increment growth resulting from defoliation. Figure 1 shows a tree disc which dramatically illustrates this effect from two previous infestations.

C. fumiferana (Clemens)

In the northeastern corner of the Province an infestation has persisted in white spruce stands since 1957. The budworm population has fluctuated from light to heavy with corresponding variations in the extent of the infestations. It appears that this is a continuation of the outbreak in northern Alberta and the Northwest Territories.

At the peak of the infestation 200,000 to 300,000 acres were infested, resulting in severe defoliation of white spruce in a number of valleys. Currently some 30,000 acres are infested although defoliation was less severe in 1974.

C. biennis Free.

The last outbreak of two-year-cycle spruce budworm in British Columbia occurred from 1946-64 in the central interior portion of the Province. At the peak of the infestation more than 8 million acres of subalpine fir and white spruce were infested. Heavy defoliation caused widespread mortality of understory trees thoughout the outbreak area. Little mortality to the overstory trees was observed, due no doubt to the opportunity for tree recovery every second year.

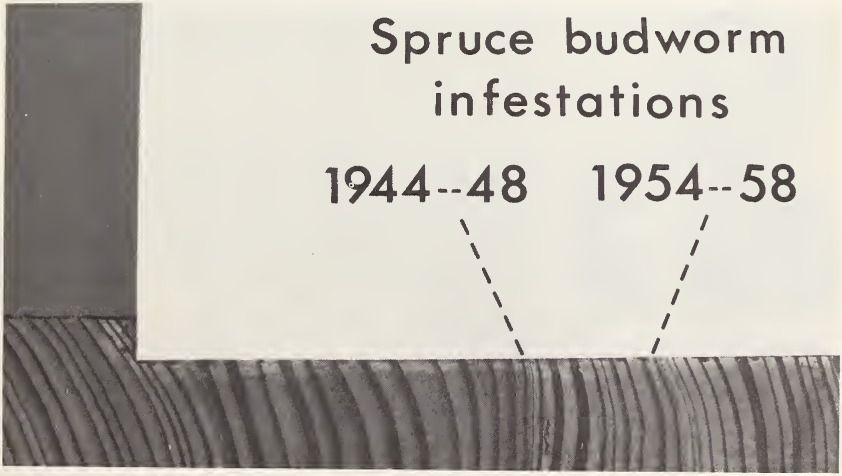
In 1974, larvae were present in sufficient numbers to effect noticeable defoliation of trees for the first time since the last outbreak declined. More than 100,000 acres of subalpine fir and white spruce were affected in the central interior of the Province, specifically in the eastern portion of the Cariboo Mountains.

C. orae Free.

A budworm infestation, apparently *C. orae*, occurred in the Kitimat River area at the head of Douglas Channel on the north coast of British Columbia from 1960 to 1964. Heavy defoliation of amabilis fir resulted over several thousand acres. It suddenly appeared in outbreak numbers again in 1969 when, in conjunction with the saddleback looper, it caused moderate defoliation of amabilis fir in the Kitimat area. It declined the following year and populations have since been very light.

FIGURE 1.

Tree disc showing reduction in increment growth resulting from spruce budworm infestations, 1944-48 and 1954-58.



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the budworm situation in the lake states - 1974

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In this review of the current situation of spruce budworm, *Choristoneura fumiferana* (Clemens), and jack-pine budworm, *C. pinus* Freeman, in the three Lake States–Michigan, Wisconsin, and Minnesota–I have asked Donald Renlund, Wisconsin Department of Natural Resources, to present the story for his State. I will summarize the situation for Michigan and Minnesota.

A third *Choristoneura* species, the large aspen tortrix, *C. conflictana* Walker, occurs in aspen, *Populus tremuloides,* over the three-State area. Serious defoliation from this pest occurred throughout most of the aspen in 1971 through 1973. Defoliation in 1974 was light and scattered; no aspen mortality has been observed. This species will not be discussed further in our paper.

C. fumiferana

In the Lake States the spruce budworm's primary hosts are balsam fir, *Abies balsamea*, and white spruce, *Picea glauca*. Black spruce, *P. mariana*, and other conifers are attacked only incidentally and when mixed with fir and/or white spruce.

Michigan

In the Upper Peninsula, a total of 94,000 acres showed moderate to heavy (50 to 75 percent) defoliation. The infestations are located at each end of the peninsula, with the major portion at the eastern end.

Infestations are generally in their third year and in most cases are in mature and overmature stands (over 45 years of age). Scattered top kill and mortality have occurred.

While tree mortality has been reported, it has not been at sufficient levels to impact merchantability standards. Many of the infested spruce-fir stands at the eastern end of the Upper Peninsula are in swamp-type terrain, making salvage operations difficult. The Hiawatha National Forest reported that limitations in harvesting procedures (i.e., size of clearcut, etc.) also affected their harvesting of spruce budworm infested stands. They reported that of approximately 100,000 cords available for marketing, some 4,000 cords were lost. The forest has been cutting about 5,000 cords annually for the past 3 years.

In lower Michigan a total of 15,000 acres of balsam fir and white spruce was moderately to heavily defoliated this summer (1974). Some top kill and mortality were reported over much of this area, but no significant losses in spruce-fir type were reported by either the State or national forests. Lack of suitable markets has made salvage difficult in some areas.

The total acreage of statewide spruce budworm defoliation was reported as 109,000 acres. Table 1 lists 1,081,700 acres of spruce-fir type in Michigan with 433,900 acres over 40 years of age.

Wisconsin

The current spruce budworm outbreak in Wisconsin dates back to 1969 when spruce-fir stands, not under intensive management, became infested. In 1974 the defoliator infested 13,860 acres in four Counties located in the northeastern and northwestern portions of the State. The intensity of this defoliation was as follows:

	Light	*Moderate*	*Heavy*	*Total*
Oneida County	2,000	2,000	7,500	11,500
Forest County	400	1,200	200	1,800
Iron County	0	500	0	500
Sawyer County	0	60	0	60
Total	2,400	3,760	7,700	13,860

Table 1. Acreage and composition of commercial forest in the Lake States

Location	Commercial forest ownership (thousand acres)					Composition of commercial forest							
						Balsam fir/white spruce				Jack pine			
	Federal	State, other public	Forest industry	Private, misc.	Total	Type in thousand acres	Percent of comm. forest	Thousand acres over 40 years old	Percent of type	Type in thousand acres	Percent of comm. forest	Thousand acres over 40 years old	Percent of type
Michigan Upper Peninsula[1]	1,636.6	1,830.7	2,152.1	3,470.6	9,090.0	872.6	9.6	—	—	412.3	4.5	—	—
Michigan Lower Peninsula[1]	857.1	2,116.0	104.6	6,732.5	9,810.2	209.1	2.1	—	—	484.3	4.9	—	—
Michigan Total[1]	2,493.7	3,946.7	2,256.7	10,203.1	18,900.2	1,081.7	5.7	433.9	40.1	896.6	4.7	261.4	29.1
Wisconsin[2]	1,592.5	2,933.7	1,368.1	8,642.5	14,536.8	628.0	4.3	333.7	53.1	727.6	5.0	140.0	19.2
Minnesota[3]	2,819.3	6,719.9	714.8	6,808.0	17,062.0	1,247.9	7.3	856.9	68.8	885.2	5.0	595.7	67.3
Lake States Total	6,905.5	13,600.3	4,339.6	25,653.6	50,499.0	2,957.6	5.9	1,624.5	54.9	2,509.5	4.9	997.1	39.6

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Egg counts indicate that moderate to heavy defoliation can be expected in 1975 throughout the area of current infestation.

The overall extent of balsam fir defoliation in Wisconsin during 1974 follows:

Defoliation	*Acres*
Light to moderate	9,200
Moderate to severe	18,200
Total	27,400

This acreage is divided about equally among Federal, State, and private ownerships.

The total commercial forest acreage in Wisconsin is 14,536,800 acres, of which 628,000 acres are spruce-fir type with 333,700 acres in age-classes over 40 years.

In Wisconsin up to 7 percent of the trees are lost after successive years of moderate defoliation, whereas 30 to 50 percent of the trees may be killed after several years of heavy defoliation. No data are available relative to the amount of top kill or growth loss caused by the budworm, although top kill appears to be substantial and it is assumed that growth loss also occurs. Recreational resource losses have been insignificant thus far.

Several years ago 30 plots were established for the purpose of monitoring budworm impact. Unfortunately, 25 of these plots have been eliminated as a result of the accelerated salvage program being conducted in areas of heavy defoliation, but we are continuing an attempt to get impact data from the remaining plots.

Wisconsin has about 1,388,000 acres of spruce-fir type distributed in small patches over 57 Counties. This comprises less than 10 percent of the commercial forest acreage in the State. Most of the spruce-fir type is broken up into small areas of approximately 200 or more acres. Because of the small stand size and the irregular distribution of this host species, the probability of having an extensive spruce budworm outbreak appears unlikely.

In the future it appears that approximately 400,000 acres in the northern Counties could be infested because of stand conditions. Favorable market conditions would permit salvaging any of the fir that might be killed there by the budworm.

Minnesota

The current outbreak in Minnesota began in 1955 and increased in size and intensity through the early 1960's. A population collapse occurred in 1964 and 1965, leaving two small residual infestations in the central portion of the Arrowhead Region in northeastern Minnesota. These two epicenters expanded from 1966 through 1971. The infestation again appears to be diminishing and moving toward the periphery of the major spruce-fir type along its southern and western boundaries.

In 1974 the following areas of spruce-fir type defoliation were reported:

Defoliation	*Acres*
Light	51,150
Moderate	83,340
Severe	82,200
Total	216,690

The commercial forest acreage in Minnesota is 17,062,000 acres, of which 1,247,900 acres are spruce-fir type, with 856,900 acres in age-classes over 40 years.

The Superior National Forest reported a total of 31,200 acres lost to spruce budworm during this outbreak, with an estimated loss of 200,000 cords of pulpwood. They also reported 520,000 cords of fir available for marketing. Their present sales program amounts to about 10,000 cords per year, and there is some indication of market improvement over the next few years. The State reported that in 1973, 4,363 acres were actually harvested out of 5,500 acres of allowable cut, producing 22,670 cords from State land only. This is an increase of 1,000 cords over 1972 and about 7,000 cords more than 1971.

Impact

Damage ranges from light defoliation to tree mortality, depending upon the age and intensity of infestation. Growth loss has occurred but no quantitative measurements of loss are presently available. Minnesota has recommended treatment of recreation sites to protect aesthetic qualities. One national forest is concerned with fir mortality and its effect on a winter yarding area for white-tailed deer. Another national forest expressed concern over stand losses of fir and the potential fire hazard. Some preliminary work has been initiated on this phase of spruce budworm impact.

Reports indicate that the major impact over the three-State area has been in mature and overmature stands of fir. Spruce has been reported as severely defoliated when intermixed or close to fir stands, although no spruce mortality has been recorded.

The extent of spruce budworm defoliation in the three States during 1974 follows:

Defoliation	*Acres*
Moderate to severe	292,700
Light	51,150
Total	343,850

The St. Paul Pest Control Group has initiated a survey to determine spruce budworm impact, based on descriptions of the tree condition. Four cluster plots around a plot center are used as the sample unit. Data are taken on all tree species within the cluster plots by five diameter size classes. Defoliation and tree condition—i.e., live, dead, or top kill—are recorded for spruce and fir. Periodic annual or biennial examinations of these cluster plots should provide a data base for developing a curve of stand attrition during the course of an outbreak. Analysis of these data could provide the land manager with the following information: (1) condition of the stand with respect to mortality and top kill of host species by size class and (2) changes in stand composition and succession.

Outlook for 1975

Infestations are expected to continue at the present level in Michigan. With probable increased market demand, harvesting is expected to keep losses at a minimum. Top kill and tree mortality are expected in areas that have been infested for several years. The rate of mortality may increase with continued heavy defoliation.

Egg-mass surveys indicate continued moderate through severe defoliation in the southern and western portions of the Minnesota infestation. Continued and increasing tree mortality is expected in those stands which have experienced three or more years of moderate to severe defoliation. A general westward expansion of the infestation is also expected.

C. pinus

The principal host of jack-pine budworm is jack pine, *Pinus banksiana.* Red pine, *P. resinosa,* is also attacked when present in infested jack pine stands.

Another important pest of jack pine is the pine tussock moth, *Dasychira plagiata* Walker. This insect has caused severe defoliation in some jack pine stands in Wisconsin and Minnesota.

Table 1 shows areas of commercial forest and host tree types in the three Lake States. Figures 1 and 2 show the ranges of balsam fir/white spruce and jack pine.

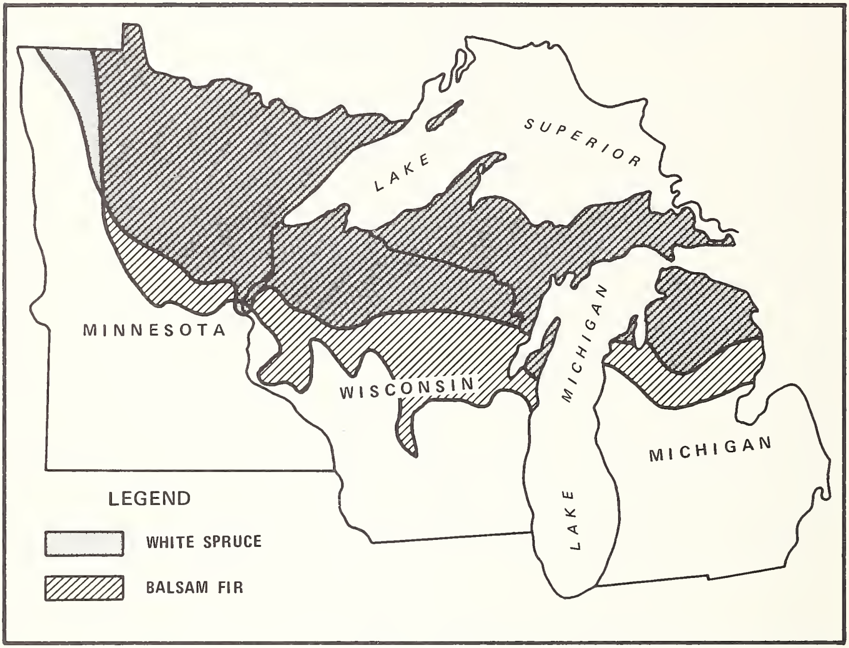

FIGURE 1.

Range of spruce-fir type in the Lake States.

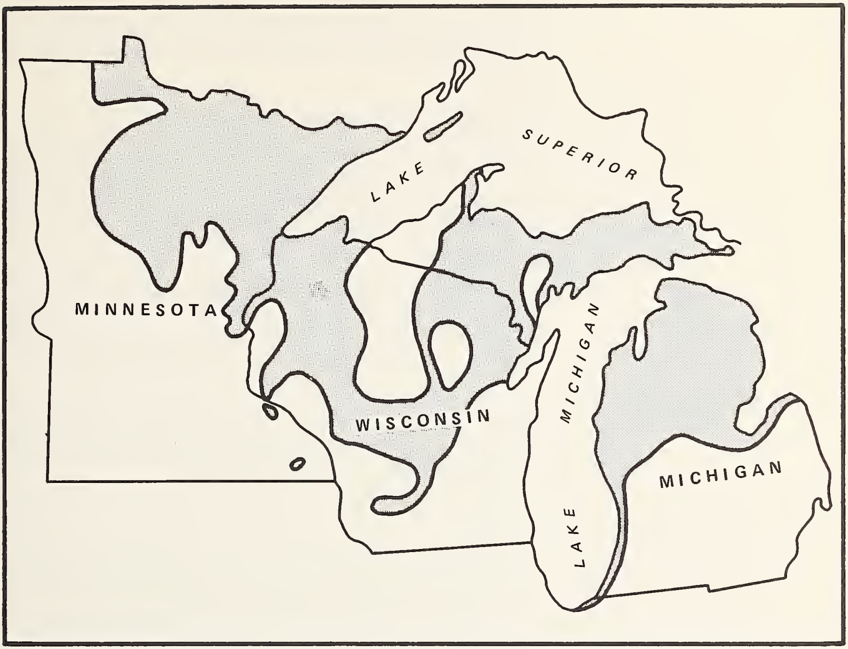

FIGURE 2.

Range of jack pine in the Lake States.

The 1974 Situation

In Michigan's 18,900,200 acres of commercial forest, 896,600 acres are of jack pine type (4.7 percent) with 261,400 acres in age-classes over 40 years old.

In the Upper Peninsula there was no reported defoliation of jack pine in 1974. In lower Michigan this budworm was reported by the State as the most damaging forest pest in 1974. Defoliation has been recorded as follows:

Defoliation	*Acres*
Light to moderate	64,000
Heavy to severe	237,000
Total	301,000

The Huron National Forest estimates that approximately 35,000 cords could be lost if none is salvaged. Sales during the past 3 to 4 years have averaged 29,000 cords per year. New market sources in the near future may increase jack pine sales.

In Wisconsin about 140,000 acres of jack pine over 40 years old constitute approximately 20 percent of the jack pine type (727,600 acres). The total commercial acreage is 14,536,800 acres. In northwest Wisconsin 12,000 acres of jack pine were moderately to severely defoliated. Egg-mass counts were low in west-central Wisconsin but no defoliation occurred.

Minnesota, with 17,062,000 acres of commercial forest, has 885,200 acres of jack pine type. Sixty-seven percent (595,700 acres) were 40 years of age or older. Jack-pine budworm is at endemic levels with no reported defoliation.

The total acreage of jack pine defoliation in the Lake States is 313,000 acres, with 80 percent experiencing moderate to severe defoliation.

Impact

Damage by the jack-pine budworm ranges from growth reduction to mortality. Defoliation at levels less than necessary for mortality causes a marked reduction in the rate of diameter growth. An equivalent of 2 years' growth may be lost during a single season of moderate defoliation. This loss is important for it affects rotation age and consequently management programs and plans. If moderate defoliation occurs three or four times during a rotation period, the rotation might need an extension of up to 8 years to produce the same quantity of fiber as would be produced in the absence of defoliation.

We have not initiated impact studies of damage to jack pine from budworm infestations.

The question frequently arises about the responsibility of forest pest management in providing the land manager with information other than that dealing with insect population trends. Should forest management provide data or limit our responsibilities to developing techniques to enable the States to provide their own information?

The 1975 Outlook

There is no outbreak anticipated in 1975 in the Upper Peninsula, since populations were low in 1974.

The outbreak in lower Michigan is expected to move into currently uninfested or lightly infested stands. As mentioned earlier, the State considers the jack-pine budworm to be the major forest pest problem with increasing potential in 1975.

No potential outbreak is foreseen for Minnesota in 1975.

Potentials for the Future

The potential for both budworm species to develop outbreaks is good in all of the Lake States. Table 1 shows that all States contain substantial acreages of spruce-fir and jack pine in age-classes over 40 years of age. Although age-class has been arbitrarily selected, it is the threshold of approaching maturity when infestations appear to develop more successfully. These older age-classes are widely scattered throughout the overall host type.

In the three-State area Minnesota has the highest percentage of spruce-fir and jack pine type in the susceptible age-class. Some of this type is in the Boundary Waters Canoe Area, where no timber harvesting activities are conducted. It is highly improbable that any insect control activities will be conducted in this area.

Until these mature and overmature stands are harvested or die of other causes, they constitute potential outbreak centers. With expanding marketing opportunities, it may be possible to reduce these hazard stands.

In Michigan 40 percent of the spruce-fir type and 29 percent of the jack pine are over 40 years old. Modifications in assigned allowable cut allotments and expanding markets can contribute materially to improving the age-class diversification.

In Wisconsin mature and overmature jack pine constitutes only 20 percent of the total type; slightly over 50 percent of the spruce-fir type is in the susceptible age group. However, expanded market opportunities coupled with increased harvesting can minimize long-term losses.

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the current situation of the spruce budworm infestation in quebec and outlook for 1975

REAL DESAULNIERS
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The spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive of the native forest insects in Quebec. The present outbreak, which began in 1967, is the third since 1910 and the tenth during the past three centuries.

The preferred hosts of the spruce budworm are balsam fir, *Abies balsamea*; white spruce, *Picea glauca*; red spruce, *P. rubens*; and black spruce, *P. mariana*.

Larvae of the spruce budworm cause considerable damage to trees by feeding on the current year's needles. Tree mortality results after 4 consecutive years of heavy defoliation.

The current spruce budworm outbreak now affects some 80 million acres of forests in Quebec, extending from Ontario in the west to the Gaspé Peninsula and the Anticosti Island in the east, and from the State of Maine in the south to latitude 51°N.

In 1974 defoliation was classified as light over 24 million acres, medium over 18 million acres, and heavy over 35 million acres. Tree mortality occurred on 3 million acres.

The spruce budworm infestation can be divided into five different sectors. The oldest one is located west of the St.

Maurice River, and tree mortality has already occurred in the Dumoine, Black, and Coulonge River watersheds. The second sector is located in the lower St. Lawrence River region north of Maine and is made up of an epicenter of heavy defoliation with light and medium areas of defoliation extending east and west. The third sector is in the Saguenay River–Lake St. John region, where defoliation is heavy except for a fringe of light and medium defoliation to the north. Light defoliation was recorded in the highlands of the Laurentide Provincial Park in the south. The fourth sector is located on the south shore of the Gaspé Peninsula. The fifth sector is in the center section of Anticosti Island just north and west of the areas heavily defoliated by the hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenée), which resulted in the loss of 3 million cords of balsam fir in 1971.

At the start of an infestation, spruce budworm populations increase in mature and pure balsam fir stands. When the insect population has reached epidemic proportions, old and young stands of fir and spruce are affected; even tamarack, *Larix laricina*, and eastern white pine, *P. strobus*, are defoliated. Tree mortality is highest in mature balsam fir stands, less on white and red spruce and the young fir trees, and practically nonexistant on black spruce.

At this time the spruce budworm has killed some 10 million cunits of pulpwood over 3 million acres. In addition to this damage, top kill has occurred over 17 million acres. Tree mortality should result in this area within 2 or 3 years.

Because of the increased number of dead trees in the western section of the Province, the forest fire hazard is very high. Fire control personnel are becoming concerned because of past fires that raged through budworm-depleted areas during the early 1920's.

The 1974 surveys indicate the insect population averages 1,772 egg masses per 100 square feet of foliage or four times more than the 1973 population level. Most of Quebec's forests are likely to suffer heavy defoliation in 1975, with the exception of the North Shore region and the northern portion of the Gaspé Peninsula, in the eastern section of the Province.

Areas of potential outbreak extend over 100 million acres. Up to 65 percent of the balsam fir and 20 percent of the white spruce are likely to be killed by this infestation. A total volume of 115 million cunits of pulpwood are expected to be destroyed in Quebec. This represents 100 million cunits on Crown lands and 15 million cunits on private lands. For the next 40 years this loss will reduce the allowable cutting of fir and spruce trees by 2 million cunits each year.

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spruce budworm situation and outlook for the northeastern united states

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In preparing this summary, the following States were canvassed and reported on in addition to Maine: New Hampshire (Al Avery); Vermont (Brent Teillon); Massachusetts (Stan Hood); Rhode Island (Rudolph d'Andrea); Connecticut (John Anderson); New York (Elmer Terrell); New Jersey (John Kegg); and Pennsylvania (Jim Nichols). Massachusetts, Rhode Island, Connecticut, and New Jersey had no known outbreaks to report; in these States, the spruce-fir type occurs only in a relatively small area in the Berkshire Hills of northwestern Massachusetts.

This report refers to the spruce budworm, *Choristoneura fumiferana* (Clemens), except for a brief reference in New York to the jack-pine budworm, *C. pinus* Freeman.

New Hampshire

No defoliation was reported in 1974, although the moth was unusually abundant in light-trap catches in the southeast and north-central areas of the State. Aerial surveys are planned for July 1975 to detect any defoliation which might materialize from these moth flights; however, no serious damage is expected. New Hampshire stands are not considered vulnerable to serious damage because there are generally no unbroken areas of spruce-fir.

Vermont

In 1974 no defoliation was detected in forest stands; activity was confined to ornamentals and scattered Christmas-tree plantations. Large numbers of moths appeared throughout the State in July and, although not new to Vermont, they were more numerous than previously experienced. Minimal sampling indicated there was egg deposition, and larval surveys were planned later in the fall and winter. No damage is expected in 1975; but if any should develop, the northern portion of the state, especially the northeast, would be most heavily defoliated.

New York

Only minor spruce budworm defoliation was reported in 1974 on 70 acres of Norway spruce plantations in southwestern New York (Chenango and Madison Counties). Heavy moth flights were observed in 1974 throughout New York (except for the southeastern area). Surveys are planned to evaluate populations in 1975 although no damage is expected. The major spruce-fir stands in the Adirondack Mountains region in northeastern New York are the main target for future outbreaks.

Jack-pine budworm has not been a problem and occurs only in jack pine plantations in Cortland County in the southwestern part of the State.

Pennsylvania

The spruce budworm became a problem in 1969 by heavily defoliating 200 acres of hemlock and causing light defoliation over several thousand acres. By 1971 moderate to heavy defoliation occurred on 52,200 acres in eastern and central Pennsylvania; tapered off in 1973; and resurged in 1974 on 15,000 acres in the north-central portion of the State.

Complete browning occurred on hemlock, Norway, and white spruce and to some degree on blue spruce. The brown needles sloughed off by late July, leaving the trees in reasonably good condition. There have been no control projects to date.

It is felt that these scattered infestations in Pennsylvania were due to a moth migration since adults were caught in light traps fully one month after mid-June, when native moths are usually finished flying. This was further confirmed in 1974 when millions of moths appeared in mid-July in several cities, especially Pittsburgh, following a strong cold front moving down from the north. Without these moth invasions, the budworm would normally pose no threat.

Maine

Maine is the only northeastern State having a serious spruce budworm problem, and we have sprayed for budworm 11 times during the past 21 years. Principal hosts of the budworm in Maine are balsam fir, white spruce, and red spruce. Black spruce is only lightly infested. Hemlock and larch intermixed with spruce-fir are seriously defoliated.

The Maine infestation is a small part of a vast infestation over several million acres in parts of Quebec and practically all of New Brunswick. This international problem was discussed jointly in 1973 and 1974 with Canadian Forestry Service and U.S. Forest Service representatives. For some time we have negotiated with Forest Protection Ltd. of New Brunswick, a nonprofit organization specifically set up to execute spruce budworm suppression projects through joint government-industry funding. They were the first to carry out aerial spraying for the budworm on a large scale, having sprayed about 200,000 acres in 1952, which was considered large in those days. We organized and financed our first spraying project of 21,000 acres in 1954, but it was executed by Forest Protection Ltd. Since then we have profited by their expertise, which enabled us to conduct projects as large as 500,000 acres. In a smaller way we have worked in New Brunswick with this organization during our nonspray years. We have gained much additional help from the Laurentian Forest Research Centre in Quebec, from the Chemical Control Research Institute in Ottawa, and more particularly, from the Maritimes Forest Research Centre in Fredericton, New Brunswick.

1974 Situation

The budworm outbreak is in the extensive spruce-fir stands in the northern half of Maine, with a rather isolated area of approximately 100,000 acres in east-central Maine which is an extension of the infestation in New Brunswick and Quebec. There is severe defoliation on over 5.3 million acres, of which 3.5 million acres are recommended for control in 1975 (Figure 1). The remaining acreage involves light to medium populations which are not typical of endemic conditions. We have not had sufficient manpower to evaluate this light to medium area.

Tree mortality to date in the 3.5-million-acre area is estimated at 758,000 cords or 0.2 cords per acre. Mortality has been kept at this low level by spraying. There has also been some top kill and increment growth has been affected, but

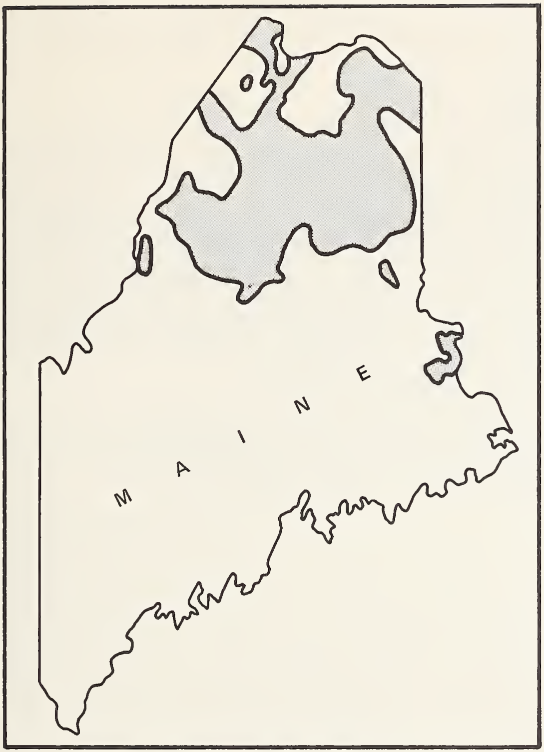

FIGURE 1.

Proposed 1975 Maine spruce budworm spray area.

under such severe conditions the primary concern is to keep trees alive. Severe defoliation occurs in trees of all ages. Some stands contained such heavy budworm populations that the 1974 buds were killed before they had a chance to open.

We have not observed impacts on other forest uses but believe that if the outbreak is allowed to go its course, it would have a strong effect on recreation, fishing, and hunting.

Fortunately we have not experienced large fires in the defoliated areas. A few years ago a fire started in a relatively small, isolated, defoliated area which quickly crowned and became very intense. Fire rangers are concerned about fire starting in extensive, defoliated areas. If the outbreak is left unchecked, dead stands may become prime tinder boxes, not only because of the large volume of combustible material but also from the drying of the forest floor where there is no shade. Later, as trees fall, accessibility to fight fires would be seriously hampered.

Outlook for 1975

It has already been mentioned that 3.5 million acres are recommended for spraying in 1975. Nearly 2 million additional acres were defoliated in 1974 and predictions based on field data indicate the same area will be seriously defoliated in 1975. Additionally, large moth flights and egg deposition in previously budworm-free stands will result in new areas of significant defoliation. Within the recommended spray area populations and subsequent damage will be intense in 1975. Egg-mass counts averaged 1,100 per 100 square feet of foliage; however, complete 1975 foliage loss would result from only 400 per 100 square feet.

Potentials for the Future

Potential areas of outbreak include all of the spruce-fir type, extending south of the present infestation and into west-central and eastern Maine.

In 1967. 92,000 acres were sprayed with DDT. However, as a compromise to the use of DDT 500-foot-wide buffer strips bordering lakes and streams were left unsprayed, and an adjacent 500-foot strip was sprayed at half dosage. This safety procedure left appreciable areas with high populations. Later it became evident that other infestations were developing, so that by 1973 defoliation was recorded on nearly 2.5 million acres. By 1974 the outbreak increased to 5.3 million acres. If control is not undertaken in 1975, the outbreak will continue to increase in intensity and extent.

Maine now faces its most serious forest problem of the last fifty years. During the outbreak of 1910-20, 27.5 million cords of fir (70 percent) and spruce (30 percent) were lost. We probably would lose at least that much again if the budworm is allowed to run its course. Maine simply cannot afford this loss because the wood industry is the backbone of the State's economy. Five companies also have expansion programs which will require an additional 600,000 cords of fir and spruce a year.

In conclusion, it is important to state Maine's policy on budworm spraying, the same policy to which Quebec and New Brunswick also ascribe: Spraying is not recommended until stands reach a critical condition and need assistance in order to survive. This policy also provides for natural control factors to exert their influence if possible.

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a synopsis of spruce budworm spray operations in new brunswick and forecasts for infestations in the maritimes in 1975

Based largely on the results of spruce budworm evaluation and hazard surveys in 1973, Forest Protection Ltd. sprayed 3.9 million acres of New Brunswick forests in 1974. Insecticides used were fenitrothion (2,416,000 acres); Dimecron (1,458,000 acres); and Dylox (33,000 acres). The results obtained with fenitrothion were comparable to results in previous years (15-60 percent foliage crop saved depending upon timing of the spray application). The foliage protection with 6.4 oz. Dylox per acre was approximately 25 percent and is equivalent to protection with fenitrothion used during the second instar of the budworms. The results obtained with Dimecron at 2 oz. per acre were poor, with only about 5 percent of the foliage crop protected. The overall average survival was a 70 percent reduction on balsam fir while new foliage saved amounted to 25 percent. Both these figures are lower than those for the past few years and reflect the poor results obtained with Dimecron.

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During 1974 defoliation surveys, 8.3 million acres of moderate to severe defoliation were recorded, an increase of 1.1 million acres over 1973. Egg-mass surveys showed that moderate- to high-level infestations covered most of the spruce-fir forests of New Brunswick (Figure 1); the largest increases

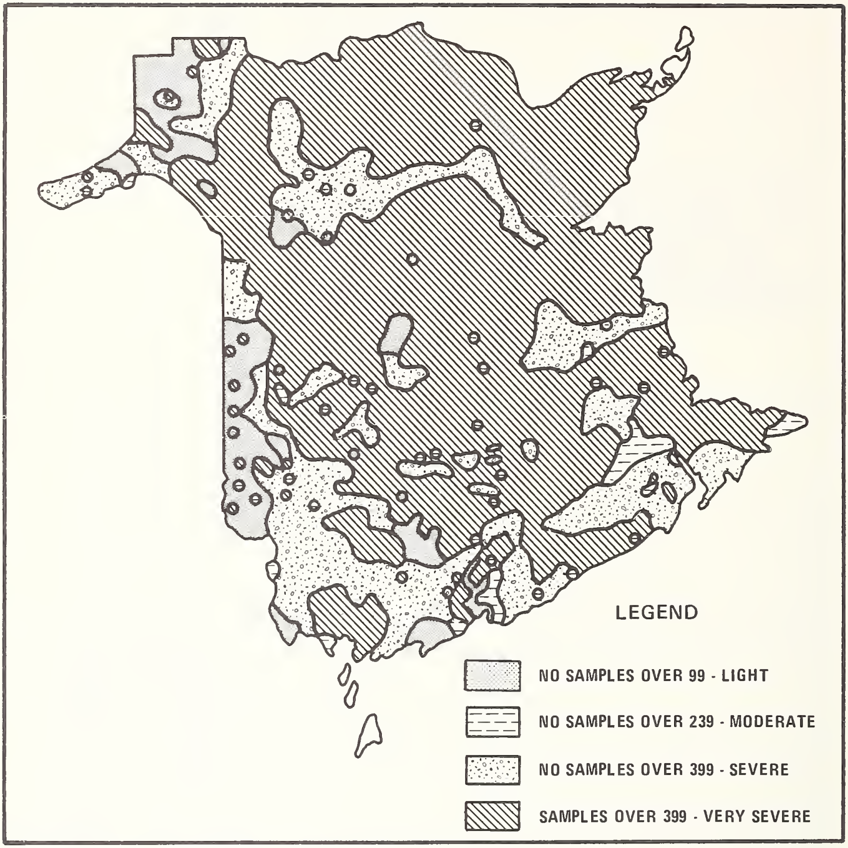


FIGURE 1.

Spruce budworm egg-mass infestations in New Brunswick in 1974.

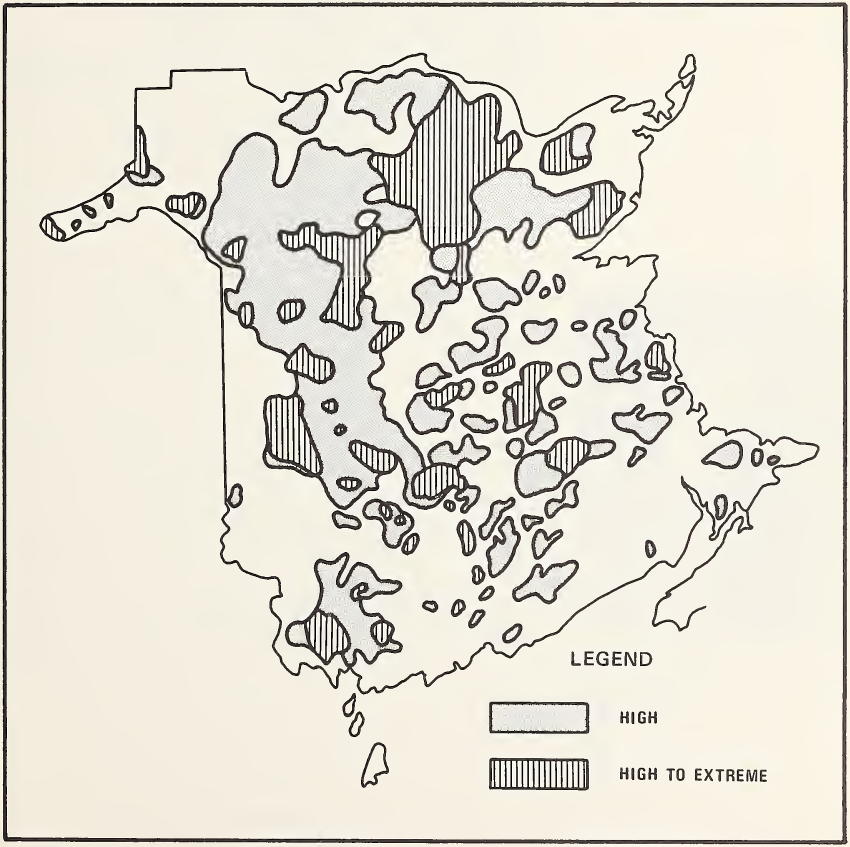
were in the northwest and southeast. Egg-mass densities increased by 50 percent over those recorded in 1973. Although the spring was generally cold and wet, weather conditions for the fourth instar to the adult stage of the budworm were excellent, and 33 percent (average) of the population reached the adult stage. Hazard to trees (as determined by Canadian Forestry Service computation) is high over 4.5 million acres and high to extreme over 2.3 million acres (Figure 2).

In Nova Scotia 380,000 acres of moderate and 87,000 acres of severe defoliation were recorded during the aerial surveys. A large proportion of this was delineated on Cape Breton Island. Egg-mass surveys indicate that the moderate to severe infestations in Cumberland, Antigonish, Victoria, and Inverness Counties have increased in area and intensity, resulting in some 1.5 million acres with a moderate to high infestation.

On Prince Edward Island aerial observers reported patches of light to moderate defoliation over the entire island, with severe defoliation affecting 47,000 acres. Evaluation surveys portend moderate to severe defoliation in 1975, which is one-half the intensity that occurred last year.

FIGURE 2.

Hazard due to the spruce budworm in New Brunswick as forecast for 1975.



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Objectives and Philosophies of Direct Control of the Spruce Budworm

Spruce budworm suppression has evolved along parallel lines in Canada and the United States. The major objectives have been to reduce populations to low levels, to prevent mortality, to protect foliage, and to protect key forest resource values.

Currently, there are only three management alternatives: Do nothing, salvage, or aerially apply insecticides.

Evaluation of suppression strategy developed as a result of our inability to institute effective and timely suppression measures. We have rarely justified treating spruce budworm on purely scientific or biological soundness, but have waited until losses have reached unacceptable economic levels.

There is a definite need to develop a course of action that will provide forest land managers options to minimize damage caused by the budworm. Some of these options might include the following:

1. Biological control.
2. Cultural measures.
3. Several chemical alternatives.
4. Combinations of the above.

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There is a profound absence of sound impact data that are needed to formulate management or suppression program decisions. Forest land managers often do not accept the spruce budworm as a problem in developing resource management objectives.

If we accept a do-nothing philosophy, then we must accept the consequence of losing valuable resources, possible species conversions, and other ecological changes which may not necessarily be compatible with management objectives.

A management system of sufficient intensity to permit harvesting and cultural measures to minimize damage over the long run may be an option which needs to be resolved.

There is a definite need for increasing our suppression technology as well as for developing methods to measure and evaluate the biological, environmental, and social impacts of the budworm. At this time, we must accept the fact that pesticides provide the only method of suppressing high budworm populations over large areas. It is imperative that every effort be taken to develop and use pesticides that are environmentally acceptable. We also need to develop alternatives to the use of these materials.

The budworm has a definite place in the forest environment, but man needs to develop a sophisticated scheme to his advantage to manage and live with the pest. This will take some time to accomplish.

Recommendations

1. Treat spruce budworm as a North American problem rather than as separate national problems.

2. Develop a committee (task force, working group, steering committee, etc.) comprised of Americans and Canadians who have the power and authority to obligate money and manpower to develop and implement a program to solve the spruce budworm problem.

3. Accept the fact that chemical pesticides are now, and will in the future, be needed to suppress budworm outbreaks for many years to come. Initiate a highly co-ordinated team effort to plan, develop, and implement a program to provide environmentally and economically acceptable pesticides for spruce budworm suppression programs.

4. Assemble a group of spruce budworm scientists as soon as possible to develop a program to resolve the first three recommendations.

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historical and present approach to spruce budworm control in the united states

Introduction

One of the first attempts to suppress an outbreak of western spruce budworm, *Choristoneura occidentalis* Freeman (formerly *C. fumiferana* (Clemens)), was conducted in Cody Canyon, Shoshone National Forest, Wyoming, during 1929-32. Lead arsenate was applied with ground equipment to "preserve life and foliage of the host trees as a means of maintaining the Canyon's outstanding scenic qualities" (Evenden, 1930).

In 1952 a trial of the effectiveness of DDT was conducted on western spruce budworm on 12,000 acres on the Sula District, Bitterroot National Forest, Montana. This effort was undertaken to evaluate methods and entomological and administrative procedures. This successful test provided a basis for large-scale suppression projects on 15 national forests and on other Federal, State, and private lands totaling 6,338,600 acres in Forest Service Regions 1 and 4 alone during the period 1952-71 (Johnson and Denton, in press). Large-scale control efforts were also undertaken in Maine, other areas of the Rocky Mountains, and the Pacific Northwest.

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Control Strategies in Early Projects

The objective of early operational control programs was to "reduce populations of spruce budworm to endemic levels in specific host forests" (Johnson and Denton, in press). This objective was tied to the target insect. Success depended on achieving high rates of larval mortality. This early objective contrasted with the Canadian philosophy described by Blais (1973) as being tied to the host rather than the insect. In Canada emphasis has been placed not on controlling the insect but on controlling the damage; that is, on keeping trees alive.

In the western United States, from 1953-58, operational control programs were organized under the concept of the "entomological control unit." This was based on the premise that reduction of epidemic populations could best be accomplished by treating entire infestations. Boundaries of "entomological control units" were either the demarcation between endemic and epidemic populations or the perimeter of the host type (Johnson and Denton, in press). The latter was particularly applicable to conditions in central and eastern Montana where extensive areas of Douglas-fir were surrounded by rangeland.

Unfortunately, the entomological control unit concept was not successful. Funds were insufficient to treat the massive acreages of infested host type. Consequently too many control dollars were deployed to areas of light infestation, while other areas of exceedingly heavy populations were left untreated.

In 1958 more effective use of limited control funds was achieved through the concept of "partial unit control." Under this system aerial spraying was directed to areas where host trees were in imminent danger of dying. This strategy undoubtedly prevented death of thousands of host trees which might not have been saved under the concept of the entomological control unit (Johnson and Denton, in press).

In the early 1960's potential adverse effects of DDT and related chemicals were being fully realized by insect control specialists, resource managers, and the general public. This led to a gradual phasing out of operational spruce budworm control programs using DDT. The last use of DDT against spruce budworm in the western United States was in 1964 on the Salmon National Forest in Idaho (Johnson and Denton, in press). DDT was used for the last time in Maine in 1967 on a project which encompassed 92,000 acres of spruce-fir forests (Coughlin, 1968).

Phasing out of DDT was coupled with an aggressive search for alternative chemicals. Malathion was used operationally until 1966. The carbamate insecticide Zectran was developed in the West and used successfully in Maine until 1974. Its high cost and limited market led to an end of commercial production early in 1974.

Higher cost of alternative chemicals together with increased public concern for the use of *any* pesticide in the forest ecosystem led to a more conservative approach to chemical spraying. In addition, the concept of benefit-cost ratio evolved where it became essential to project benefits derived from a proposed action and compare them to estimated costs of the action. Lack of sound data on the effects of spruce budworm defoliation on resource values led to an even more cautious approach to aerial spraying. Emphasis was placed on documentation of the effects of spruce budworm epidemics on timber, watershed, recreation, and other forest resource values (Ciesla et al., 1973; Bousfield et al., 1973; Franc et al., 1973).

Present Approach to Control

Our current philosophy of spruce budworm control is a dynamic and changing one. It is tied to the ever-changing values of the resource base, public pressures and desires, and our capability to assess the course and impacts of an epidemic and to conduct an effective control program. A decision for or against control is based on the following:

1. A biological evaluation of the potential for a continued epidemic of the pest insect.
2. A benefit-cost evaluation.
3. An assessment of environmental impacts of both the outbreak and action alternatives.

These evaluations plus an examination of positive and adverse effects of several alternatives, including the alternative of *no* action, lead the resource manager to a sound decision.

The ideal spruce budworm control strategy is to identify key resource values of the land–both timber and nontimber; project the adverse effects of continued defoliation; compare these impacts with the cost of a control effort; and arrive at a sound decision. Unfortunately our capability for collecting the data required for this type of analysis is currently limited. In Maine, strategy for a control effort proposed for 1974 was stated as follows: "To delay treatment until required for tree survival permitting natural control factors to exert influence effectively. Only areas showing heavy cumulative damage–60 percent or more for two years—will be considered for treatment" (USDA Forest Service, 1974).

Effectiveness of Spruce Budworm Suppression Programs

Traditionally our approach to spruce budworm suppression has been to time aerial application with the appearance of fourth- and fifth-instar larvae. The insect's habit of infesting buds during early larval instars, thus making it a poor target for contact aerial sprays, has dictated this strategy. Our desire to achieve high larval mortality has caused us to sacrifice considerable foliage during the year treatment is applied and has made it difficult to assess benefits derived from the treatment.

Measurements of success or failure of operational control programs directed against spruce budworm are extremely complex. They may be broken down into two types, immediate and long-range benefits. Immediate benefits include an assessment of prespray and postspray larval densities with the computation of percent control. Another immediate benefit which can be readily measured is the effect of the treatment on subsequent generations of the target pest: Do egg-mass surveys show a significant reduction in defoliation potential or is treatment needed the following year?

More difficult is an assessment of foliage saved as a result of the treatment. This is directly related to long-range benefits of the control action in the degree of mortality, top kill, etc., it prevents. Ciesla et al. (1971) demonstrated that large-scale color infrared aerial photographs were effective in assessing foliage saved by aerial application of experimental materials designed to control the forest tent caterpillar, *Malacosoma disstria* Hübner, in Alabama. Detailed foliage assessment procedures were developed in conjunction with operational and pilot control programs against Douglas-fir tussock moth, *Orgyia pseudotsugata* McDunnough, in the Pacific Northwest in 1974 (Bousfield, unpublished data). This involves comparing regression of prespray population densities and subsequent defoliation in spray blocks and unsprayed checks by covariance analysis. These techniques may also be applicable to the spruce budworm.

Some Unanswered Questions

Several questions continue to frustrate the resource manager and the insect control strategist when planning control operations against the spruce budworm. Under our present approach of spraying late-instar larvae, what is the minimum acreage which can be effectively protected? Earlier it was pointed out that spraying late-instar larvae did not necessarily protect foliage. This being the case, a high degree of larval mortality is necessary to reduce the potential of the subsequent generation in order to protect foliage in year N + 1. We also learned that mass migrations of spruce budworm moths are a result of epidemic populations. Therefore, treated areas are subject to reinvasion the same year they are treated.

A corollary consideration is the number of years an area can be protected by a single aerial application before adult migration and resident population buildups again result in population densities capable of causing significant feeding injury. Spruce budworm epidemics are long lived, lasting as long as 16 years in the northern Rocky Mountains. With this in mind, several aerial applications of an insecticide may be necessary in order to adequately protect the stand during an outbreak cycle.

Today the resource manager has three basic alternatives when faced with a spruce budworm epidemic:

1. Do nothing; accept the consequences of the outbreak.

2. Salvage dead and dying timber to partially recover losses.

3. Use chemical sprays.

Additional options are desperately needed to cope with this massive problem. Cultural treatments designed to reduce stand susceptibility to spruce budworm epidemics are needed for long-term protection of the forest resource.

Biological controls are needed to protect ultrasensitive resource values such as fisheries. Several chemical alternatives are needed to give the resource manager a wide choice of options dictated by environmental considerations, public opinion, control strategy, and a more recent problem—shortage of specific chemicals. With this in mind, the primary objective of any research and development effort on spruce budworm must be to increase the number of forest pest management options available to the resource manager.

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historical sketch of the philosophy of spruce budworm control in canada

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The spruce budworm, *Choristoneura fumiferana* (Clemens), has been a serious pest of the spruce-fir forests of eastern North America since before the turn of the century. The eastern pulp and paper industry has sustained serious losses extending well beyond this span. Budworm attacks not only kill trees within 3 to 5 years of extreme defoliation, but also increase the threat of vast fires as an aftermath to epidemics.

Studies concerning the insect are now in the fifth generation of Canadian researchers: first by Totthill, Craighead, and Swaine in about 1912; the second generation, Graham, Dowden, Flieger, Balch, and Atwood; thence to the third, Blais, Belyea, Fettes, Morris, Henson, Wellington, and Angus; then to the fourth of Miller, Randall, Greenbank, and Buckner; and finally to the fifth and presently active group, consisting of Kettela, Sanders, Howse, and Desaulniers. Many innovative approaches have been undertaken over the years: management practices, chemical protection, and biological and integrated control. Canadian researchers have undoubtedly led the way in research on the life history, ecology, physiology, and population dynamics of this and other economically important insects. Nonetheless, we must report that our scientists, in a study span predating World War I, have learned very little about *infestation dynamics.* In the final analysis, over the past six decades we have attained no viable spruce budworm management strategies.

In Canada, chemical budworm control began after World War II with the advent of the "wonder chemical," DDT, and the availability of surplus military aircraft that could be converted to aerial spray vehicles. With these two powerful management tools we began naively to "exterminate" the budworm from our forests. In the Province of New Brunswick as early as 1951 the threat of another series of infestations was recognized and the forest industry was convinced that future losses could not be tolerated without protection. Although some reports indicated there were hazards to fish, beneficial insects, and wildlife, it was concluded that 1 pound of DDT per acre could control the budworm without presenting undue hazard to nontarget fauna.

In the innocence of the time of the first New Brunswick spray program—a modest 200,000 acres—and with several years of control experience in the United States to draw on, the beginning of the New Brunswick program was approached with confidence and without real fear of undesired consequences. There were only those few references suggesting that aquatic fauna might be upset at a mere 1 pound per acre; certainly not of sufficient concern to initiate comprehensive studies on fish and wildlife, or even on nontarget insects or residues. When the operation increased to several million acres, however, and included an important salmon-producing river, we suddenly realized that the fry of 1954 were missing and the only explanation seemed to be the DDT spraying. By this time the dosage had been reduced to 1/2 pound per acre for purposes of economy as much as for other reasons. And so the tenacity of the budworm and economic necessity altered our "impossible dream" of extermination to a strategy of suppression to endemic population levels.

Technological advances in spray equipment, availability of more suitable aircraft, and developments in the agricultural chemical industry gradually changed the budworm control picture. By 1958 a program to discover an effective substitute for DDT was underway, and many promising chemicals were tested first in the laboratory and later, if successful, in the field. The carbamates and the organophosphates were emerging as agricultural insecticides, and several of these showed some of the desired characteristics of control chemicals. The organophosphates appeared suitable, being systemic to some degree and short lived, with toxic residues lasting for only several weeks. The breakdown products were insignificantly toxic in either quantity or quality. The carbamates were also promising, being only moderately toxic to aquatic and terrestrial vertebrates, short lived, and very effective.

By 1966 an organophosphate was being applied along the rivers and lake shores in an effort to avoid water contamination by DDT. By 1969 phosphamidon was being used on larger portions of the areas to be treated; however, investigations continued with other materials in the event unwanted side effects appeared. Such was the case with phosphamidon, which proved to be somewhat toxic to birds even at the very low recommended dosages. Another organophosphate, fenitrothion, proved to be marginally less toxic to birds, enough that it could be safely used in amounts effective against the budworm. The way was then clear to replace DDT with fenitrothion (1970), since it showed no significant effect on fish and was relatively innocuous to most other forms of life at application rates of 4 to 6 ounces per acre.

At the same time, yet another "philosophical change" was emerging in budworm control strategy. Fostered again by economic necessity and the invincibility of the budworm, lower chemical dosages were applied to infested forests. In consideration of the toxicity of these new chemicals to nontarget organisms, coupled with insecticide cost and budworm tenacity, there emerged the "philosophy" of foliage protection rather than budworm control. Along with these developments, recent Canadian use of huge multiengine aircraft for budworm control, equipped with sophisticated inertial navigational equipment, has brought us to the present state of technology and strategy. Because of chemical shortages another philosophy has arisen, which is to save the high-value, aesthetically sensitive or short-term cutting-plan stands and to let the rest go.

Another wave of experimental management plans is now underway. From the technological standpoint one bad feature of aerial spraying is the shortness of ideal flying time during daylight hours. With time lost because of unfavorable weather and pressured by the inexorable development of the target pest, operations almost invariably extend beyond the optimum spray period for adequate control. Most nonturbulent air conditions occur at night, and with the advent of electronic guidance it is reasonable to consider night spraying as a practicable option. Night spraying has already been tried but not without visual aids. The modification of available systems for aircraft guidance at night is currently being developed.

At the same time experimental use of bacteria, viruses, hormones, growth regulators, and pheromones shows some promise of increasing the suppression arsenal. These may be applied singly, in combination, or sequentially, providing a promise of new and brighter approaches to the problem. The case for the use of parasites, predators, diseases, and ecologically less harsh materials is indeed worthy of investigation. These tools are barely on the horizon, however. Their development as viable spruce budworm management tools continues to be hampered by an unwillingness to raise the problem to a priority level sufficiently high to produce adequate resources for a solution—if a solution is a reasonable expectation.

A "new look" in budworm infestation management is emerging. Our goals have generally been dictated by the budworm, economics, and environmentalists and not by forest managers. However, with increasingly more effective insecticides and technical expertise, and with the prospect of early detection of outbreaks by satellite photography and by the detection of moth distribution and movement by radar, the emphasis is shifting. In the past we have concentrated on "population dynamics" to unravel the budworm problem. It seems likely, however, that "infestation dynamics" might logically be applied to bring a more useful, modern, and up-to-date approach to the problem. In the Sanders' discussion, Pest Management Strategy of Epicenter Control, which must be associated with "infestation dynamics," we might explore alternative strategies dictated by forest managers. Because the budworm occupies an ecological niche independent of political boundaries, the most sensible and profitable solution would be a *group* management approach to the *common problem*.

11

pest management strategy of epicenter control

At present the only effective method of managing outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clemens), is to protect foliage by the annual application of chemical insecticides. The disadvantages of this technique and the desirability of developing alternative strategies for managing the insect-forest ecosystem are obvious. One potential alternative is to detect and suppress outbreaks before they reach extensive proportions. If the origin of an outbreak is localized in small, discrete areas, i.e., epicenters, then the suppression treatment will be simpler and cheaper, and will involve smaller quantities of insecticide than are required for foliage protection.

An epicenter may be defined as a discrete area of forest that supports more rapid insect population growth than the surrounding forest, under favorable climatic conditions and by nature of its topography and stand condition. Populations in such an area escape density-dependent control factors and attain sufficient density to disperse into surrounding stands, thereby causing outbreaks in forest areas which by themselves could not support the rapid population growth necessary to trigger an outbreak. The final clause here is crucial; if the surrounding forest could support the development of an outbreak without invasion from an epicenter, then treatment

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of the potential epicenter would not prevent an outbreak, it would merely delay it.

The antithesis to the theory of epicenters as sources of outbreaks is the hypothesis that population densities increase over broad expanses of forest, likened to a rise in the ground swell of population fluctuations. If this is the case, then a suppression program is still feasible. However, it would have to be conducted over much larger acreages, making the decision of when to spray far more critical than in a smaller operation such as suppressing an epicenter, where the expense and environmental hazard of spraying several times are not as serious.

It is probable that under different conditions outbreaks start in different ways; under some conditions outbreaks may arise from epicenters, and under others from a rising ground swell. The picture is further confused by the time element. If favorable climatic conditions persist long enough, outbreaks may develop synchronously over extensive areas. If the favorable conditions are of shorter term, however, populations may escape endemic control mechanisms only where population growth is fastest; i.e., in epicenters, which can then trigger outbreaks in the surrounding forests by dispersal. Thus, the origin of outbreaks may vary not only from one locality to another, but also under different conditions in the same locality.

If the suppression of epicenters is to be a valid strategy for regulating budworm populations, then two questions must be answered. First, do epicenters exist? And if so, how do we recognize then? The answer to the first question is still debatable, but the available evidence suggests that in at least some instances outbreaks have arisen from discrete areas; the best documented instance being the Lake Nipigon outbreak of the 1940's. In two other instances prompt action contained what appeared to be incipient outbreaks while they were still in localized areas. The first was in an area of 100 square miles in the Kedgwick Lake area of Quebec (Blais, 1963). The second occurred in 430 square miles in the Burchell Lake area of northwestern Ontario (Sippell et al., 1969). In both instances, however, other factors in addition to chemical insecticides contributed to the collapse.

How do we recognize epicenters? Presumably they are areas of favorable stand conditions—uniform, relatively pure, mature white spruce and balsam fir—and favorable topography—where budworm survival is enhanced and dispersal losses are low, possibly south-facing slopes or areas subjected to fewer storms or air turbulance than adjacent areas. Such areas may be of any size, ranging from a few hundred acres to hundreds of square miles. The more broken the topography and the more variable the climate, the smaller the area. Therefore, in coastal, hilly areas epicenters may be measured in hundreds of acres. In inland areas of low relief and continental climate, such as the Midwest and Ontario, epicenters are likely to be much larger, grading into a situation indistinguishable from a rising ground swell in budworm populations.

A serious attempt to test the theory that epicenters do exist and can be defined was started recently in northern New Brunswick. Unfortunately the test area was invaded by a moth flight which masked any local effects. However, the theory is of sufficient importance to warrant serious consideration of another attempt. The Canadian Forestry Service is considering northwestern Ontario for study, the only area at present free from outbreaks of the spruce budworm in eastern Canada. Part of the problem with such a study is the high cost in time and money of larval sampling in such low-density populations. Sex attractant traps may provide sufficient information to allow us to cheaply monitor population fluctuations. The advantages to budworm management of being able to define and locate epicenters, which can be relatively cheaply suppressed, are such that research into their detection should be of high priority.

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12

protection of selected forest resources (crop protection) as a management strategy

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It is not my intention in discussing this strategy to defend it, nor to attack it; only to briefly describe and document its use and the results.

Within the continuum of available strategies and variations that extend from "do nothing" to total population control, the strategy of "crop protection" or "protection of selected resources" lies somewhere near center. Many variations exist in Canada and the United States in the implementation of this strategy; therefore, it is difficult to find examples of the clean or classic approach—perhaps none exists. The principal variation comes about in the selection of resources to be protected and the timing of protection. Some followers have used pure economic criteria and have aimed the protection or prevention of intolerable damage at highly valued and used recreation areas, high value stands, and the like. Others have applied the philosophy to areas harboring the highest populations and/or highest levels of cumulative damage or threat of damage, which implies that there are no value differences between stands.

One factor on which all practitioners agree is that in following this strategy their efforts are not aimed at insect eradication or even population control over the entire area of infestation, but rather at controlling damage—keeping trees alive.

Since this strategy does not include total treatment of an infestation, it follows that the philosophy perpetuates the survival and possible subsequent enlargement and dispersal of populations in the untreated infested areas. If this enlargement and dispersal does not occur, it is because of natural control factors (cool, wet weather during spring larval emergence, starvation, or loss of oviposition sites), all of which occur independently of the suppression decision and unfortunately are largely unpredictable.

Another factor that should be considered in assessing this strategy is that even under the best of conditions, all mortality is not prevented. It is an accepted fact that rootlet mortality can exceed 75 percent when loss of new foliage approaches 100 percent. This obviously inhibits the ability of trees to obtain moisture and nutrients from the soil, forcing a reduction in their stored starch reserves particularly in older and mature trees. Proper timing of spraying then becomes critical because if we wait too long to initiate protection, the objectives may not be met.

Through a review of the pertinent literature, it appears there have been situations in northeastern United States and eastern Canada in which the strategy seems to have worked—at least temporarily. The first large-scale operation in eastern North America to save pulpwood stands from destruction by the spruce budworm, but not to suppress the total outbreak, took place in the early 1950's. Based on defoliation and egg-mass surveys, it was apparent that extensive mortality would occur in some areas in northern New Brunswick, Maine, and eastern Quebec unless insecticides were used. Only a fraction of the total infested area was treated each year; the criteria for annual selection being those areas that had suffered 2 years of severe defoliation and harbored high egg-mass counts. During the life of the infestation, re-invasion of some of the annual spray blocks occurred. These were re-treated, generally after 2 years.

When the spray program was initiated in 1952, it was hoped the forest could be kept alive and that natural control factors, along with spraying, would eventually end the outbreak—and that is what happened. Cool, wet weather during 1956 and 1957 caused significant reduction in the budworm populations in Quebec. The final collapse of the outbreak, occasioned by additional pressure from parasites and predators, occurred in 1958.

By 1959, budworm populations were once again endemic in Québec and northern New Brunswick; however, the infestation in central New Brunswick and northeastern Maine persisted. These infestations spread, and for the past 15 years portions of the total infestation have been sprayed annually. If a "do nothing" policy had been followed, extensive losses would have occurred some years ago and by now the insect would have returned to the endemic status because of lack of food. Natural control factors have not been effective. It can now be said that although chemical control has the ability to prolong the life of trees and prevent loss, it may also prolong the duration of the outbreaks. A review leading up to the present Maine situation may help put this thought in perspective.

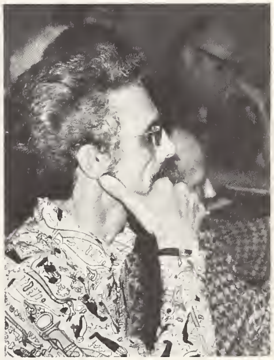
Maine has adhered to the strategy of spraying only when the trees need treatment to survive. This policy was reasonably effective before 1974; at least extensive mortality was prevented. In the past 20 years spraying was done in 1954, 1958, 1960, 1961, 1963, 1964, 1967, 1968, 1970, 1971, 1972, and 1973. There are a few gaps so it is difficult to say whether we were dealing with one outbreak or several. In that same 20-year period, little or nothing was done to reduce the vulnerability of approximately 40 percent of the 8 million acres of spruce-fir type in Maine; vulnerable because it is in the mature to overmature age categories. At the present time 5 million acres are infested and treatment is proposed on 3.5 million acres.

Periodic spruce budworm epidemics are a natural consequence of a temporary imbalance within the boreal forest—an overabundance of balsam fir in the older age-classes over large areas. This situation, if uncontrolled, will be changed by the spruce budworm but at the expense of an undefined impact on the wood resource and related economy.

Losses from spruce budworm can be minimized by periodic expenditures, not necessarily on the same acres; perhaps annual expenditures will be necessary until weather factors or starvation cause a general population collapse. Treatment with chemicals is a pragmatic approach; in fact, spraying maintains the status quo and does nothing to alter the basic problem. The question then is whether the periodic treatment costs during rotation can be justified by the prevention of impact on the economy. Prevention of damage to the resource (trees) is not the same thing. We do not yet know how much actual loss can be absorbed before significant impacts to the economy occur.

13

the consequences of applying no control to epidemic spruce budworm in eastern spruce-fir



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This paper describes the events in three stand conditions typical of a 40-square-mile area of eastern spruce-fir that was not protected from a spruce budworm outbreak in 1949-59.

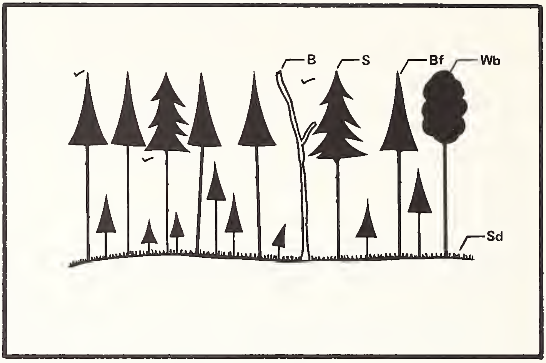
First Stand Condition

In old-growth conifer in 1949 (Figure 1a), the original 80-year-old stand consisted of 600 to 800 stems per acre, 138 sq. ft. of basal area, 70 ft. tall, containing 15 to 30 cords of merchantable pulpwood per acre. The stand contained 79 percent balsam fir, 11 black spruce, 6 white spruce, 2 yellow and white birch, and 2 other deciduous species. Most of what had been about 5 percent of the basal area in white birch had been killed by birch dieback in the previous decade. The mature fir had been flowering and seeding for 30 to 40 years, and some advance reproduction had been established where light conditions were suitable. In the 7 years before the first heavy defoliation in 1950, heavy flowering had resulted in the establishment of 400,000 to 500,000 seedlings per acre. They contained the future of the stand.

The stand sustained heavy defoliation for the first 3 years, with little effect other than a reduction in growth. When lar-

FIGURE 1a.

Original stand with fir, white and black spruce, and birch overstory; fir and spruce understory less than 40 years; and carpet of seedlings less than 7 years old.



ABBREVIATIONS FOR FIGURES

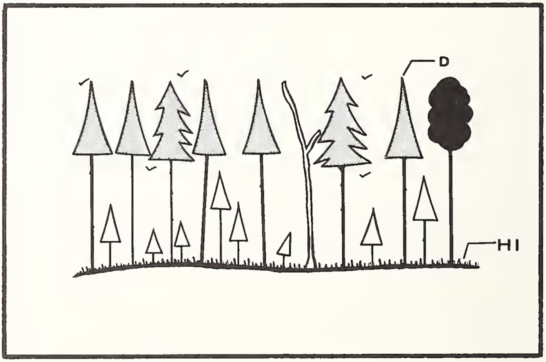
B: dead birch stem; S: white and black spruce; Bf: balsam fir; Wb: white birch; Sd: balsam fir and spruce seedlings; D: severely damaged crown; Fd: dead fir; HI: pin cherry, white birch, mountain ash, or yellow birch; H: white birch, yellow birch, red or sugar maple.

vae exhaust food in the overstory before reaching maturity (common in the second and third year) they drop to the understory. Advance reproduction, possessing limited foliage complement, is fed upon severely. The seedlings escape—larvae that reach the forest floor are eaten in a short time by mice, voles, and shrews.

In the fifth year, the first mortality began among the advance growth and the suppressed and intermediate stems in the overstory (Figure 1b). Germination and growth of raspberry, pin cherry, white birch, and mountain ash commenced on the forest floor, shading the very small seedlings as strong sunlight began to penetrate to the bottom of the stand. Through these 4 years, bird populations expanded 1.7-fold, and pine marten became common—probably the result of the abundance of small mammals.

FIGURE 1b.

Stand after 5 years of defoliation. Overstory severely damaged; understory dead; seedlings beginning to grow, together with cherry, white birch, mountain ash, and raspberry.



By 1956 there was a low budworm population but the fir had suffered irreversible damage. Rootlet mortality was severe, the ability of the trees to set buds was severely limited, nutritional reserves were exhausted, and sunlight had elevated soil temperatures. By 1959 (Figure 1c), mortality of overstory fir was complete—no trees survived but the small seedlings, white and black spruce, and hardwoods. Spruce seemed to escape for two reasons: It is able to form buds at any point where a branchlet has been excised, and the foliage develops much more rapidly than fir in the early spring, thus yielding small larvae feeding on large shoots. Bird populations declined as the trees died and the species composition became mainly ground dwellers.

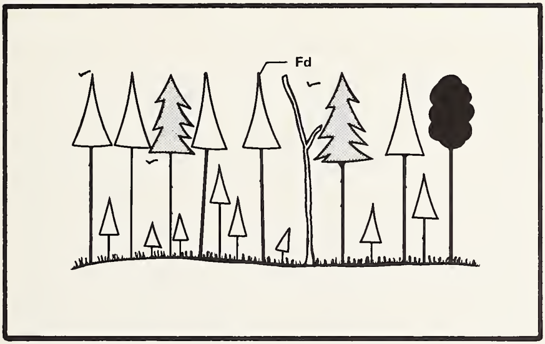


FIGURE 1c.

In the ninth year all overstory and understory fir is dead; seedlings and hardwoods continue to develop; overstory spruce begins to recover.

As this stand develops, 15 to 20 years later it consists of a very dense understory comprised mostly of fir, some intolerant hardwoods, and a small proportion of spruce; an overstory of spruce and surviving birch; and decaying stubs of dead fir and birch (Figure 1d).

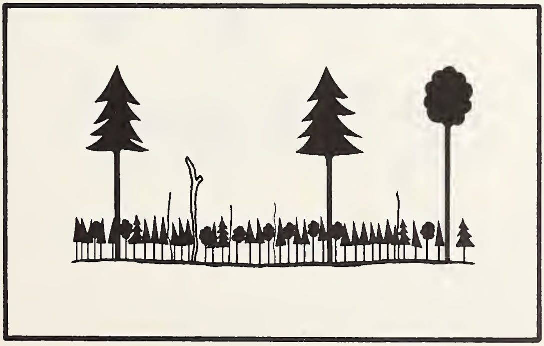


FIGURE 1d.

About 20 years after (a), the surviving spruce in the overstory have recovered; conifers in the seedling population have emerged to form a new, very dense stand; and decaying remnants of the stems of the original stand are still to be seen.

Second Stand Condition

Forty years after the original defoliation, a dense young stand of the same composition exists, with 2,000 to 5,000 stems per acre, just beginning to flower (Figure 2a). For reasons lost in history, these two age-classes, the 40 and 80, exist throughout much of eastern spruce-fir contemporaneously, and budworm outbreaks occur each 40 years. The origin of the 40-year-old from the 80 has been traced. While attack on the mature stand is producing the results described above, somewhat different results are produced in the adjacent young stands. The attack builds in much the same fashion as in the mature stand, with lighter attack initially, but with higher populations in the third and fourth years when foliage is depleted in the mature stand but some is still being produced in the young stand. There is a severe reduction in foliage complement in the young stand, radial growth is reduced, the tops of the main stems are killed, and there is some rootlet mortality, but only about half of the trees are killed. Trees that lie beneath the spruce overstory are more likely to die because of increased feeding from larvae that drop, while trees near hardwood crowns gain some protection via either reduced feeding pressure or the benefits of shading on the root systems during the stress of defoliation and consequent soil heating. The future stand consists of the survivors (Figure 2b); there are few seedlings. Mortality is distributed almost equivalently across size-classes. The stand may benefit from the thinning. In the next 40 years the overstory spruce drop out and the mature stand is reproduced. Thus budworm plays a central role in the establishment and development of even-aged spruce-fir.

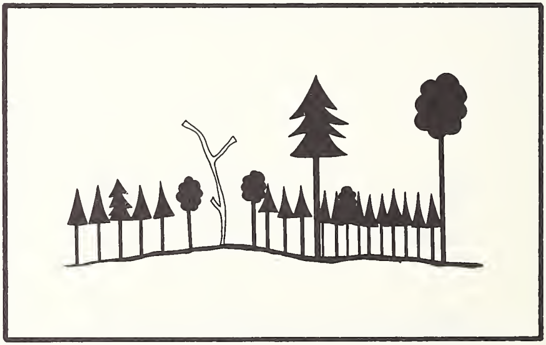


FIGURE 2a.

Original stand.

Third Stand Condition

The third typical condition consisted of all-aged mixed wood, probably all-aged because it was mixed. The stand consisted

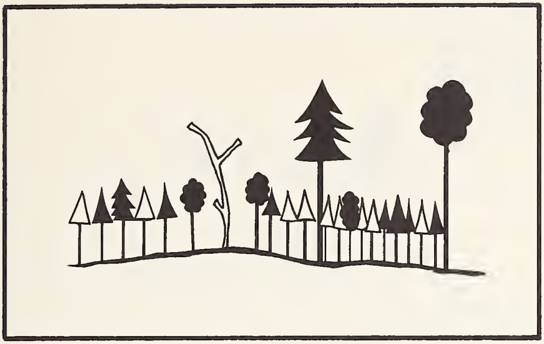


FIGURE 2b.

Stand 12 years after first attack; damaged crowns have recovered. Trees are labeled as in Figure 1.

of white spruce and balsam fir, with red and sugar maple, and yellow and white birch, with the conifers making up about 40 percent of the stand. The largest fir were about 135 years old, and age ranged throughout the younger age-classes (Figure 3a). In this stand type, defoliation was as severe as in the other two stands with two differences—there tended to be a greater intensity on the large exposed dominant crowns and on the smaller conifers beneath overstory conifers. Conifers surrounded by hardwood crowns and beneath hardwood tended to experience less feeding pressure. In addition, these mixed-wood stands possessed a well-developed shrub layer, mainly mountain maple, which, combined with the hardwood component, tended to sustain shade over the root systems. These, and possibly other, factors resulted in less mortality than in the mature conifer, distributed over the several age-classes and thus propagating the all-aged condition (Figure 3b). In the other stands, particularly the mature conifer, mortality resulted in less variation in age than existed originally.

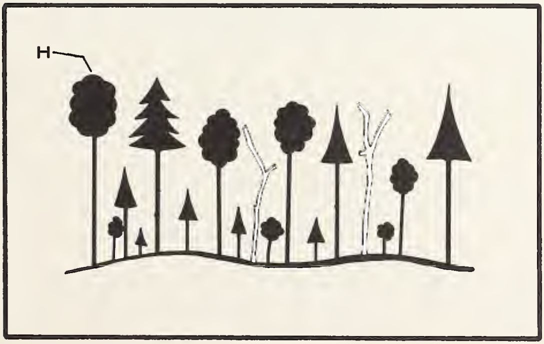


FIGURE 3a.

Original stand.

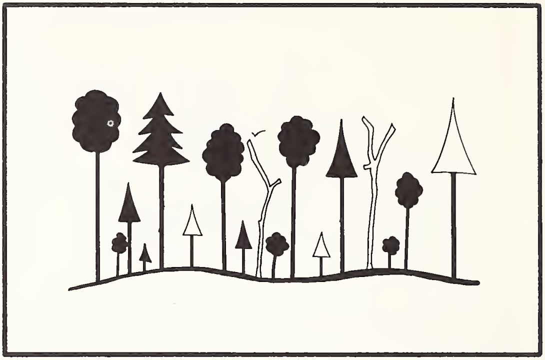


FIGURE 3b.

Twelve years after first attack. Trees are labeled as in Figure 1.

Findings

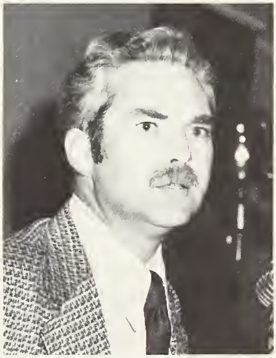
Studies of factors related to variation in the degree of mortality were conducted throughout the 40-square-mile area. Regression analyses revealed associations between the proportion of stand mortality and measures of proportion and size (or age) of balsam fir, and distance from noninfested areas. Mortality increased as the proportion and size of balsam fir in the stand increased. Stand mortality increased as the distance increased in the average downwind direction from several miles of clearcut area. An increase was also noted in the upwind direction from areas treated with insecticide. These results can be explained in terms of larval and adult dispersal downwind without replacement from the uninfested areas—predominantly in the direction of the prevailing winds, and to a lesser extent in the opposite direction. The regression equations accounted for 49 percent of the variation in the data in the first year of mortality, declining to 30 percent in final mortality. It is likely that the results provide a basis both for rating hazard of damage to existing areas and for regional management to reduce future hazard.

III

Control Methodologies Available or Planned for Near Future

1. Chemical Insecticides and Application Methodology

The need for chemical insecticides for budworm control is critical. Only two materials are registered for use against budworms in the United States—Zectran and Malathion. Zectran is no longer available and Malathion sometimes poses environmental hazards. A vigorous laboratory and field testing program is needed for an orderly research and development process to provide an array of chemical insecticides to meet various forest management objectives. Continued developmental work is needed to improve application technology. Much is to be learned about dispersal of applied materials, and continued improvement could greatly increase effectiveness and reduce environmental hazards.



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Recommendations

Laboratory screening and bioassay activities should be expanded to provide better baseline data to guide the selection of materials for field testing.

Field testing should be accelerated to evaluate the efficacy and environmental safety of more chemical insecticides for budworm control. Emphasis should be placed on current or potential agricultural chemicals. Potential systemic insecticides for special uses should be more fully evaluated. Materials should be tested against both the spruce budworm and the western spruce budworm. Consideration should be given to developing relatively "standardized" field test designs, sampling methods, and measures of efficacy.

U.S. investigators should learn the Environmental Protection Agency's policy on accepting data from Canada and other countries for registration of materials in the United States. This should be determined before work plans are finalized for the 1975 field season.

Developmental work on application technology should be continued and expanded.

2. Microbial Insecticides

Microbial insecticides offer potential for spruce budworm control but none is ready for operational use. The efficacy of *Bacillus thuringiensis* looks most promising, but better application methods could probably improve its performance. Experience in Canada indicates that spruce budworm viruses, particularly the nucleopolyhedrosis virus, may be useful in some pest management strategies.

Recommendations

Developmental work on *Bacillus thuringiensis* for budworm control should be continued, with emphasis on application technology.

Research on spruce budworm viruses should be strengthened, with emphasis on the nucleopolyhedrosis virus. The search for new budworm viruses should continue, particularly in populations of the western species.

3. Parasites and Predators

Of the natural enemies of the various budworm species, parasites and predators have received the most attention. However, the emphasis has been on determining their roles in population dynamics. Generally they are recognized as contributory but seldom, if ever, determining factors. There is little hope of using parasites and predators in a biological control context against the budworm species.

Recommendations

Monitoring nontarget organisms, particularly parasites and predators, should receive emphasis in biological evaluation (presuppression), suppression programs, and postsuppression evaluations. The monitoring program should be an integral part of the planning, execution, and evaluation of operational programs.

4. Silvicultural Control

For many years silvicultural treatments have been suggested to reduce the hazards of spruce budworm outbreaks to host stands. Implementation of such practices has been slow and incomplete. In the West, forest practices unrelated to the western spruce budworm may have important implications in terms of the effects of budworm outbreaks.

Recommendations
Large-scale evaluations of silvicultural treatments now believed to reduce the hazard of budworm outbreaks should be undertaken.

Forest practices should be evaluated to determine their eventual effects on the nature and degree of budworm damage.

5. Attractants, Juvenile Hormones, and Feeding Deterrents

Extensive investigation in Canada and in the United States has demonstrated the usefulness of budworm attractants for survey purposes. Much is to be learned about the potential of this approach to control, even in special situations. Some juvenile hormones appear to have considerable potential for budworm control in some pest management systems. Feeding deterrents are largely unexplored.

Recommendations
Research and development on sex attractants for various budworm species should be continued to more fully develop their potential for surveys and to explore their usefulness for control.

Work on growth regulators should be continued, with particular emphasis on gaining more efficacy data and general experience with a few materials now closest to registration.

Research should be undertaken to explore budworm feeding deterrents for possible use in pest management systems.

6. Integrated Control (Integrated Pest Management Systems)

Research, development, and application efforts addressing the budworm problem should be brought together in an integrated pest management system. All aspects are interrelated, and the systems approach is most appropriate for developing pest management strategies compatible and suitable for a variety of forest management objectives. An urgent need exists for improved impact assessment methodology. "Impact" should be broadly considered to include the full range of forest resources and values.

Recommendations

Improvement of impact assessment technology should be assigned high priority and should emphasize the effects of budworm outbreaks on stand dynamics, stand and site characteristics, and associated resource values rather than just effects on trees (mortality).

A co-ordinating structure should be developed to bring together the various research and development efforts on budworms in the East and the West. Mechanisms should be established for improved international co-ordination and co-operation.

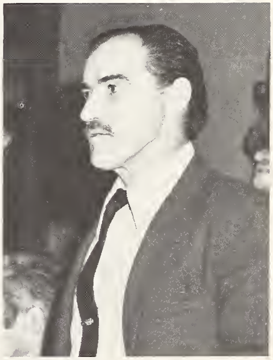
14

insecticides, formulations, and aerial applications technology for spruce budworm control

I am very pleased to have this opportunity to renew old acquaintances and to exchange some of our findings on the subject of pesticides, formulations, and spray technology currently used on large spray operations against the spruce budworm in Canada. This particular topic merits considerable attention in view of the continuing expansion of the spruce budworm epidemic. Much of the information I will present was obtained through the co-operative efforts of the pesticide industry, the Provincial and Federal Government agencies of Canada and the United States, and other personnel who assisted in the collection of scientific data over a large number of years. If there are pertinent omissions or gaps in the data, they are unintentional.

Insecticides, Toxicity, and Formulations

The spruce budworm, *Choristoneura fumiferana* (Clemens), is by far the most important forest insect pest in Canada and has been responsible for a high degree of defoliation, suppressed tree growth, and mortality of balsam fir and spruce. In the absence of natural control agents to suppress epidemic populations of the budworm, man is forced to apply insecticides to protect the softwood forests. Past records of insect



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epidemics have shown that natural agents cannot protect the forest from partial or total destruction following severe infestations. Once the decision is made to protect the forest by chemical means, then all efforts should be concentrated on providing the best pesticide, formulation, and application technology in order to ensure the desired deposition of the toxic agent uniformly over the target area.

Let us consider the chemicals that are currently used for spruce budworm control. One must concede the fact that when a chemical compound is classified as an insecticide, a considerable amount of time, effort, and money has been spent by the pesticide industry on laboratory screening and pilot field tests, to ascertain its efficacy against a group of test insects. Further testing by scientists has narrowed the field to a specific toxicity rating for a particular species of insect. The establishment of lethal dose toxicity values (LD_{50} and LD_{95}) for a particular insecticide product against insects, birds, fish, and other biological fauna provides a guideline for the use of that material. In addition these values delineate the parameters for effective dosage levels for the insect pest and other biological fauna in the ecosystem. To exceed these levels on operational spray projects constitutes a waste of material and the possibility of environmental repercussion.

In the case of the spruce budworm the choice of chemical insecticides is quite broad, as shown in Table 1. Group A represents those highly effective materials that have passed numerous experimental field trials and are currently being used on an operational basis in Canada at concentrations effective against the budworm, yet relatively harmless to other biological species. Group B includes those materials that have been used on a semioperational basis. Highly effective materials of an experimental nature are listed in group C. Group D represents the alltime favorite DDT that is now banned from use in Canada (except under very exceptional circumstances). Group E represents one of the successful biological agents that is currently being used operationally against the spruce budworm and other insect pests.

Fenitrothion, Matacil, and Zectran, the three most popular materials, have LD_{95} values of 0.654, 0.157, and 0.153 $\mu g/cm^2$. These values indicate that these compounds are extremely effective against budworm larvae at very low dosages. By comparison, the LD_{95} for DDT would range from 7 to 44.3 $\mu g/cm^2$, indicating that considerably more material would be required to achieve insect mortality at corresponding mortality levels. The LD slopes for these materials are shown in Figure 1. The steeper the slope lines and displacement of the line to the left of the chart, the greater the toxi-

Table 1. Toxicity of insecticides used on experimental and operational spray projects for spruce budworm control

Category	Insecticide	Toxicity rating[1] spruce budworm 48 hrs. ($\mu g/cm.^2$)		Calculated deposit (oz./acre) based on LD_{95}	Field dosage (actual)			Biological toxicity LD_{50}[2]		
		LD_{50}	LD_{95}		Active ingredient (oz./acre)	Number of applications	Volume/ application (oz./acre)	Mammals—rat oral (mg./kg.)	Birds—mallard oral (mg./kg.)	Fish—trout (p.p.m.) LC_{50}
A	fenitrothion	0.333	0.654	0.93	2.0	2	16 - 20	250	1,190	3
	Matacil	0.049	0.153	0.22	0.75	2	16 - 20	50	22.5	10
	Zectran	0.041	0.157	0.22	0.75	2	16 - 20	19	3.0	10.2
	phosphamidon	0.403	0.744	1.10	2.0	2	16 - 20	27	3.0	8
	dimethoate	1.053	4.199	5.99	2.5	2	16 - 20	215	41.7	19
B	Malathion	—	3.923	5.57	3 - 6	1	20	1,375	—	—
	Dylox	—	1.121	1.60	6 - 12	1	20	450	105	12
C	Lannate	—	—	—	1	1	4 - 16	17	15.9	> 1.0
	pyrethrins	0.04	0.11	0.17	0.25	1	4 - 16	200	10,000	0.054
	pyrethroids (SBP-1382)	—	—	—	0.15	—	4 - 16	—	—	—
	Orthene	0.42	3.5	5.0	6 - 12	1	20 - 64	945	350	1,000
D	DDT	1.99	8.3 - 44.4	12 - 60	4 - 16	2	20 - 128	113	2,240	0.007
E	*Bacillus thuringiensis*	—	—		6 - 8 BIU[1]	1	64 - 256	nontoxic	nontoxic	nontoxic

[1] Nigam (1969, 1974).

[2] Compiled from numerous sources (available on request).

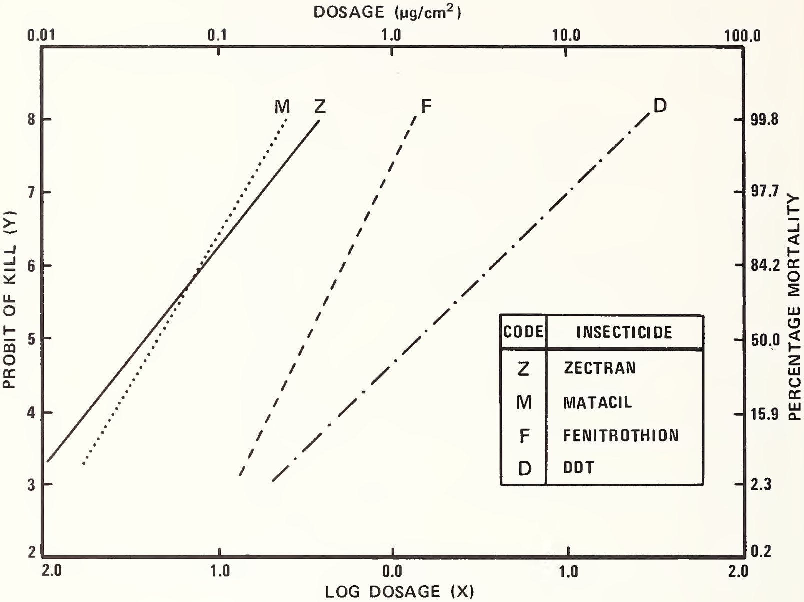

FIGURE 1.

Comparative Ld-p lines of insecticides against fifth-instar *Choristoneura fumiferana* (Clem.) for 72 hours after treatment.

city or efficacy of the compound at increasing concentrations (Nigam, 1969, 1974).

Extrapolation of LD_{95} toxicity data in terms of spray deposits on an acreage basis would provide calculated values of 0.22 oz. per acre for Matacil and Zectran, 0.93 oz. per acre for fenitrothion, and 10 oz. per acre for DDT. These values are *not real*, since they do not represent a three-dimensional area such as foliage on a standing tree, but rather a flat acre surface. These values could approximate an acre of forest foliage which in the final analysis is the insect habitat or target site.

The physical and chemical properties of each insecticide provide a guideline of the parameters for potential formulations. Calibration and field trials then establish dosage levels for a type of formulation to be used under operational conditions. These would include parameters for spray emission height, swath width, and meteorological conditions. Scientific data collected over the years have shown that excluding the development of insect resistance to a particular compound, insecticides are consistently effective against a given species of insect at the established toxicity values. Failures encountered in operational spray programs must therefore occur because of factors other than lack of efficacy of the insecticide.

There are numerous reports of poor kill or inadequate control using the most effective insecticides available. Obviously the insecticide failed to reach the target site at concentrations lethal to the insect. Time does not permit me to discuss all the permutations and combinations of why a material failed to control a given species on a particular program, but a large degree of chance can be eliminated if the following key factors are considered.

1. Insecticides should be selected and formulated to the specific task required; i.e., don't use an agricultural spray formulation for forestry use unless the pest, crop, and conditions of application are similar.

2. Use the proper aircraft and spray equipment for the job and then calibrate the equipment using the proper formulation to ensure the desired drop spectrum size and spray coverage.

3. Should a change of formulation occur, recalibrate the equipment.

4. Check the equipment, formulation, and application techniques under conditions similar to those expected on operations.

Application Equipment and Spray Technology

The technology of a spray program is influenced by the insecticide formulation used and the requirements for adequate spray coverage. An example of the changes made in operational procedures for spruce budworm control during the past 44 years appears in Table 2. These data could also be presented from a technological point of view by outlining aircraft spray capabilities as in Table 3.

Table 2. Examples of changes made in operational procedures for spruce budworm control, 1930-74

Year	Insecticide	Formulation	Equipment	Rate	Swath (feet)
1930-44	arsenical	dusts	hopper	20-40 lb./acre	60
1945-60	DDT/oil	low conc.	booms and nozzles	1-3 GPA	90-200
1960-65	DDT/oil/H_2O	high conc.	booms and nozzles	20 oz./acre	300-400
1965-70	ULV conc.	technical	rotary atomizers	2-10 oz./acre	100-400
1972-74	ULV conc.	high conc.	open nozzle boom	12-20 oz./acre	3,000

These data reflect the changing technology of spray operations and the influence of insecticide formulations, spray equipment, aircraft, and spray project size, that in turn generate a change of strategy.

Early spray operations were small and hence, by nature, not complicated. As the infestations increased in size more aircraft, pilots, and airfields became necessary, with a corresponding increase in complexity of the whole spray operation. The introduction of the TBM "Avenger" aircraft in 1956, with its faster speed and greatly increased payload resulted in a more efficient operation (Randall, 1957). However, the basic techniques of spray application, dosages, calibration techniques, and aircraft tracking used for Stearman aircraft were retained. Introduction of the TBM aircraft resulted in a reduction in cost per acre, while at the same time permitting larger acreages of forest land to be protected during an equivalent timespan.

Table 3. Aircraft spray capabilities

Capabilities	Stearman 1950-60	TBM 1957-74	DC-6, DC-7, Constellation 1049 1972-74
Air speed (m.p.h.)	90	170	230
Swath width (yards)	30 to 60	150-300	1,000
Rate of flow (gal./min.)	20	60	200
Dosage rate (gal./min.)	1; 0.5;0.19	0.19	0.19
Acres/min. (approximate)	20 to 40	160	1,280
Spray block size (acres)	960	5,000	76,000 +

Further increases in budworm infestation made it imperative that spraying operations must once again expand, so that pesticide applications could be successfully achieved during the critical stages of spruce budworm development.

To meet these increasing requirements, more aircraft, airfields, and facilities would be necessary or, alternatively, a new class of spray aircraft with a higher payload capability and an increased spray application speed would be essential. When considering all aspects of large-scale forest insect control programs, changes in strategy and techniques often have more relevance than the expanded use of current and perhaps somewhat outdated equipment and/or methodology. A recent case history of such an outbreak occurred in the Province of Quebec. In 1967 a moderate spruce budworm infestation was discovered in a 4-square-mile area. In 1968 the infestation had increased considerably. By 1969 moderate to severe defoliation was recorded over a 3-million-acre area. By

1971 the overall infestation had increased to 12 million acres. In 1972 approximately 2 million acres of the infested area were sprayed. Aerial photographs of the forests in July 1972 indicated a potential infestation of 20 million acres for 1973, of which 5 to 10 million acres would suffer severe defoliation.

With control recommendations calling for two spray applications, the second to follow the first by 10 days, the total area to be sprayed was, in effect, doubled. The use of small aircraft on a spray program of such magnitude would require the construction of numerous additional airfields and service roads in a wilderness area. The colossal task of providing such facilities is readily apparent.

The alternative to meet this challenge would seem to be an updating in spray equipment capabilities and application techniques. The logical choice to meet this challenge appears to be a merger of ULV droplet production with high volume emission and change in flight pattern over the terrain.

Incremental Spraying and Equipment Calibration

The theory of the dispersal of spray droplets in a two-dimensional plane by wind and gravity was proposed by Gunn (1948), and adopted by others. The principle known as the Porton Method allows the creation of effective swath width dimensions, limited only by the effective height of spray release and the source and volume of spray droplets and volatility of the formulation. Unpredictable factors such as changes in wind velocity or direction, air temperature, cloud cover, lapse or inversion condition, and patterns of airflow over terrain can alter the effectiveness of swath widths.

To ensure maximum deposition on all target surfaces with a minimum probability of over- or underdosed areas, spray deposition should be the accumulation of spray drift from emission passes of an incremental nature rather than the immediate result of the downwash from a single pass (Randall, 1969, 1974). Large-scale forestry spraying for such insect pests as the spruce budworm therefore should utilize the drift component of spray applications to transport the lower end of the spray droplet spectrum across and into the forest canopy. Here the small droplets can be screened out of the air by the fir and spruce needles, to ensure maximum biological activity over a period of time (Himel and Moore, 1967).

The ability of the open nozzle to produce a very fine droplet spectrum similar to that of the rotary atomizers (i.e., MMD 70 to 80 μ) at equivalent rates of flow allows the use of more nozzle per foot of boom and thus a far greater output of ULV spray drops. Changes in spray application technology therefore are directly related to the drop size and drop numbers of the spray; i.e., large drops result in a narrow swath width with high volume delivery and low coverage in terms of acreage. To achieve the transition of high volume to ULV application using the boom and nozzle system, a change of concept from drop production by hydraulic pressure to that of air pressure utilizing aircraft speed and wind shear was required. Boom configurations on aircraft were usually placed in areas of low drag such as the trailing edge and under the wings rather than in areas of clean airflow. These areas were selected to economize on fuel consumption rather than efficiency of spray drop production. Droplet production was primarily achieved by fluid pressures; thus calibration of aircraft spray equipment usually consisted of rate of flow calibration to standardize duration of spray emission. This step was essential to ensure uniformity of spray emission time per aircraft carrying equal payloads (Figure 2).

FIGURE 2.

Rate of flow calibration on a Grumman Avenger (TBM) spray aircraft.

The low pressure open-nozzle system, on the other hand, depends upon the interaction of two fluids (air and liquid) in the proper proportions and contact angle. A source of non-turbulent high speed air (such as that occurring on the top surface of the wing of an aircraft) is essential for such a system.

The successful adaptation of such a system on the DC-7B multiengine aircraft (Figures 3, 4, 5, 6) provided the basis for future development and refinements in ULV droplet production (Randall and Zylstra, 1972). In 1972 the first multiengine sprayer aircraft fitted with electronic navigation equipment (Litton LTN-51) and utilizing the incremental drift

FIGURE 3.

Douglas DC-7B multiengine spray aircraft equipped with above-the-wing booms and open-nozzle system.

FIGURE 4.

Closeup of above-the-wing spray boom as fitted to a DC-7B aircraft.

FIGURE 5.

Calibration run of the DC-7B aircraft and spray system for droplet spectrum size and drift deposit.

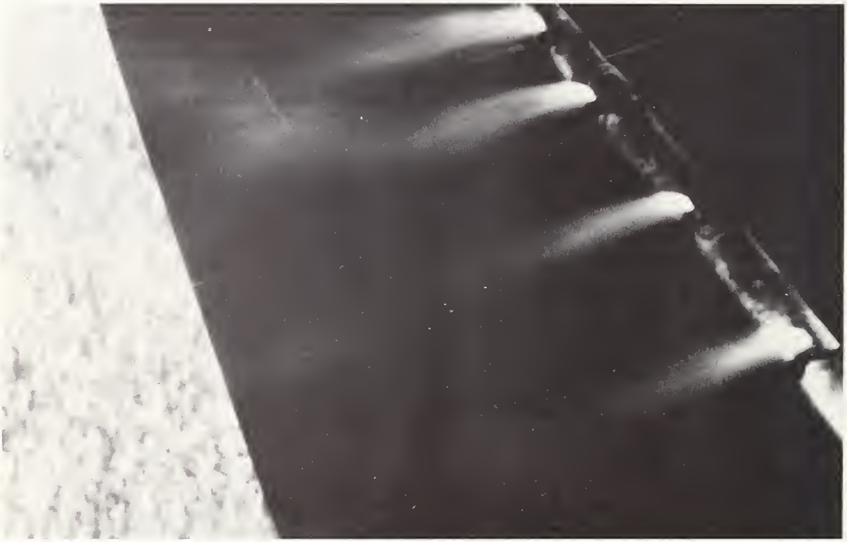

FIGURE 6.

Closeup of the open-nozzle system during active spray emission.

technique of spray application was successfully used in the Province of Quebec against the spruce budworm (Figure 7) (Randall, 1974).

Sufficient data were obtained from the DC-7B field trials to confirm the applicability of the incremental technique of aerial spraying and to assess the value of the Litton inertial guidance system to locate the desired co-ordinates of flight lanes and successfully increment 3,000-foot swath intervals, from these established co-ordinates. Further studies under-

FIGURE 7.

DC-7B spray aircraft in operation.

taken with the co-operation of the Quebec Department of Lands and Forests; Conair Aviation Ltd., Abbotsford, British Columbia; and Aviation Specialties, Mesa, Arizona, on the open-nozzle spray system and boom placement on the upper surface of the wings of multiengine aircraft revealed that boom location and nozzle placement were critical for ULV droplet size production. Subsequently a Canadair CL-215 aircraft was released by the Quebec Department of Lands and Forests for research and development to establish boom location and nozzle position for optimum ULV droplet spectrum size and numbers (Figure 8). Results of these trials led to the development of the airflow indicator (Figure 9) and the establishment of critical contact angles for the open air atomizers and the preference of forward mounted boom on the wing surfaces.

FIGURE 8.

Calibration of nozzle angle of the open nozzle as fitted to a Canadair CL-215 aircraft.

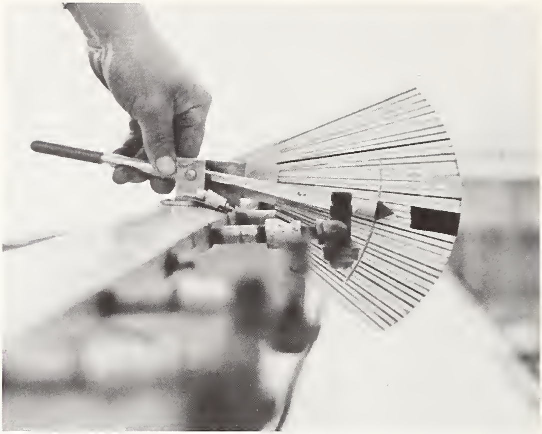

FIGURE 9:

Development of an airflow indicator for use with open nozzle for accurate setting of nozzle angles.

In the following year studies were initiated on the Douglas DC-6B (Conair Aviation Ltd.) and confirmed on the Constellation 1049 (Aviation Specialties) that uniformity of spray column height and boom pressure were a prime requirement for ULV droplet production, as shown in Figures 10 and 11. Thus it became imperative that aircraft spray equipment require proper calibration and deposit assessment prior to use on operational projects.

FIGURE 10.

Rate of flow calibration of individual nozzle showing the variation of flow rates through the nozzle before calibration.

FIGURE 11.

Final adjustment of rates of flow for nozzle to achieve uniformity of ULV droplet spectrum characteristics.

Summary

In the past few years a highly sophisticated program of forest protection has been evolving in Canada, particularly in the Province of Quebec, in the field of aerial application of pesticides for the control of the spruce budworm. Combination of application techniques, such as the Porton Method of spraying (Gunn, 1948), ultra-low-volume drop spectrum production (Sayer, 1959), and incremental spraying using open-nozzle equipment, multiengine aircraft, and electronic guidance control, has paved the way for new concepts of insecticide usage. The future for aerial application appears to be both highly challenging and rewarding in efforts to conserve one of Canada's natural resources.

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15

the status of chemicals for suppression of spruce budworm in the united states

A number of insecticides show considerable promise as potential candidates for suppression of spruce budworm, *Choristoneura fumiferana* (Clemens), and western spruce budworm, *C. occidentalis* Freeman, populations. Candidate materials with the characteristics desired for budworm suppression are generally of three types: transitory, residual, or systemic.

Transitory insecticides are highly toxic to the target insect. They degrade rapidly in the environment, breaking down generally in a day or less. Examples are pyrethrins, many pyrethroids, and such organophosphates and carbamates as phoxim and methomyl. The strategy necessary for effective use of transitory materials is to apply the insecticide to exposed mature larvae—usually in the fifth or sixth instars. Direct contact with the insect is critically important because no significant residual action can be expected. This strategy would probably result in more foliage destruction by the larvae compared to an early spray application against second- and third-instar larvae, but the ephemeral nature of the insecticides would materially aid in minimizing environmental hazards.

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Residual insecticides produce a significant toxic effect after deposit on the host foliage, generally lasting from a few days to several weeks. This degree of residual life contrasts with "persistent" insecticides, such as DDT, in which deposits may be active for several months or longer. Examples of residual insecticides are carbaryl (Sevin) or trichlorfon (Dylox). Direct contact with the larvae is supplemented by the added bonus of residual biological effects as the larvae feed on the treated foliage. Although still of paramount importance, timing and precision of spray application are less critical than with transitory materials. Timing of spray application would probably be similar to that used for transitory materials. A residual insecticide may pose a somewhat higher environmental hazard than a transitory material with similar toxicological properties.

Systemic insecticides would be applied in an "early" strategy aimed at suppressing the larval population when it is largely in the second and third instars, while concealed in needles, buds, or newly expanding foliage. This strategy would be expected to save more foliage than a late-instar spray and would minimize tree damage.

At the Pacific Southwest Forest and Range Experiment Station, Berkeley, California, we have screened more than 180 basic chemicals. More than two dozen of these candidates show sufficient promise to warrant advanced evaluation. We recently began a second level of laboratory bioassays to fully characterize the activity of selected candidate materials and formulations. These studies include feeding bioassays by using diets fortified with the test insecticide, spray chamber tests of the contact action of field or commercial formulations on larval stages, and studies of residual action by using potted Douglas-fir seedlings.

Most Promising Candidates

Our evaluations and research by others to date suggest at least eight candidates warrant some kind of field testing in 1975. Selection was based on a combination of the following criteria:

1. High toxicity to the target insect.
2. Potentially high environmental safety.
3. Significant, but not persistent, residual action.
4. Previous experience in the field against the budworm.
5. Registered uses for agricultural or other pests.

All of the eight following candidates are as toxic, or more toxic than Malathion, which is presently registered for budworm suppression. I am assuming Zectran is no longer commercially available. Zectran is presently registered for budworm suppression but its manufacture has been discontinued.

1. Aminocarb (Matacil), a carbamate, is a short-term residual insecticide with some systemic action, is similar to Zectran, and is toxic to the western spruce budworm (LD_{50} by topical application) at 1.3 µg./g. body weight. (Zectran is toxic generally at 1 to 2 µg./g. in repeated tests.) This insecticide has been applied in Canada on the spruce budworm. It will probably be registered there for that use by the end of 1975.

2. Orthene is a water-soluble organophosphate systemic with short-term residual action. It is toxic at 27 µg./g. (Malathion is toxic at 29 µg./g.) Orthene has an excellent safety profile. It has been tested in the field on the spruce budworm in Canada.

3. Chlormethylfos (Dowco 214) is an organophosphate with appreciable residual action. A derivative of Dursban, it is toxic at 1.6 µg./g. Except for fish, it is generally of low toxicity to vertebrate organisms.

4. Fenitrothion (Sumithion) is a water-soluble organophosphate systemic, toxic at 4 µg./g. It is hazardous to birds, but no serious environmental impacts have been observed at 4 oz. per acre or less. Field experience includes applications on the spruce budworm in Canada and Maine. The compound is registered for use on the spruce budworm in Canada.

5. Methomyl (Lannate), a transitory, water-soluble carbamate toxic at 2 µg./g., has been tested on spruce budworm in Canada.

6. FMC 33297 (NRDC 143) is a chlorinated pyrethroid, toxic at 1 µg./g. It has an appreciable residual life—unusual for a pyrethroid.

7. Carbaryl (Sevin) is a carbamate toxic at 20 µg./g., with a long residual action and appreciable stomach action. It has been field tested against the spruce budworm in both the United States and Canada.

8. Trichlorfon (Dylox) is a short-term residual organophosphate, toxic at 20 µg./g. It is registered in Canada for use against the spruce budworm, and it has

been tested in California on the Modoc budworm, *C. viridis* Free.

This is not a complete list of promising candidates. Other materials, such as pyrethrins, resmethrin, and phoxim, are transitory materials that also have considerable potential.

Field Testing

The station's Insecticide Evaluation Project has prepared tentative plans for field testing four candidate materials—aminocarb, Orthene, methomyl, and carbaryl—using two different treatment strategies. The first strategy is an early application using aminocarb and Orthene against larvae, mainly in the second and third instars, to exploit the systemic action of these materials while the insects are hidden in buds and newly expanding foliage. The aim of this strategy is to save foliage and minimize tree damage.

The second strategy is a later application of aminocarb, methomyl, and carbaryl against the exposed older larvae, mainly fifth and sixth instars. A late spray strategy will exploit the high contact toxicity, residual action, or both these qualities, but will also sacrifice foliage.

These field tests are designed to:

1. Determine and compare the field efficacy of the four insecticides and two strategies. (Efficacy will be measured by budworm mortality and residual population densities and by the amount of foliage protection.)

2. Determine the effects of the various treatments on parasites of the budworm larvae and pupae.

3. Determine the effects of the various treatments on nontarget arboreal and terrestrial insects.

4. Obtain additional safety data for treatment effects on fish, birds, and small mammals.

5. Determine the persistence of the materials in crop and browse plants.

I would like to elaborate on our selection of Orthene for field testing because this insecticide represents a new approach in the control of defoliators. We have developed in our laboratories, under the leadership of Dr. Carl E. Crisp, the concept of "acid activation" by which systemic compounds can be made to transport with the photosynthate in phloem tissue. Commercial systemics are largely xylem mobile, translocating with the water in xylem tissue.

Many important groups of insect pests feed partly or wholly in phloem tissue; therefore, they are uniquely subject to suppression by chemicals that display phloem mobility. Such pests include sucking insects, shoot and tip moths, cone and seed insects, bark beetles, and defoliatiors that feed on newly developing foliage.

Phloem transport offers an effective means of suppression. It can be exploited in two ways. The first is suppression of cambium feeders, such as bark beetles, by fall applications to mature, "hardened" foliage while phloem transport is downward in the tree. The second is suppression of insects feeding on newly developing tips, shoots, cones, or foliage in the spring while phloem transport is upward in the tree toward these areas of rapid new growth.

The problem of developing phloem mobile systemics is to tailor the molecule to penetrate living cell membranes in the plant and to move with the assimilate stream in phloem tissue. Crisp has analyzed the functional groups that correlate with phloem transport. He found that carboxylic or phosphoric acids correlated best with phloem mobility and also their amines or esters, which are transformed to acids in the plant.

We have examined 140 compounds, but only two commercial materials—Orthene and Monitor—show some degree of phloem transport. And only 5 to 10 percent of the applied dose of each material will transport in the phloem. However, we now know it is possible to increase phloem transport substantially because one of our own compounds, IEP-99, transports to the extent of 35 percent.

One advantage of acid activation is that phloem mobile compounds can be designed so that they are nontoxic until transformed to an active ingredient in the plant. This characteristic provides an unusual degree of environmental and human safety. Two examples are an experimental phloem mobile systemic produced by Stauffer Chemical Company called R-29534 and our own IEP-99.

What then are the prospects for spruce budworm suppression with phloem mobile systemics? I think they have an excellent potential as early sprays while larvae are feeding in expanding buds and shoot tips.

Orthene is well along in commercial development; it has been well researched for environmental safety and could probably be registered in the near future as soon as sufficient efficacy data are generated. Orthene is as toxic as Malathion on spruce budworm; Malathion is currently registered for use on this insect. Orthene is twice as toxic to the western spruce budworm as it is to the Douglas-fir tussock moth. A field test against the tussock moth in 1974 showed Orthene was effective on this insect.

I suggest that the Forest Service proceed with an aggressive, well-funded series of field tests on both the spruce budworm in the East and the western spruce budworm. This applies also to laboratory testing which provides the data needed in designing and executing sound field evaluations. We should seek to eventually register three or more materials for budworm control to provide flexibility in choosing suppression alternatives to fit local management objectives.

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status of microbials for control of spruce budworm

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Of the microbial agents isolated from or tested against spruce budworm, four are presently receiving considerable attention from researchers: (1) microsporidia; (2) fungi, principally *Entomopthora*; (3) virus, particularly nuclear polyhedrosis virus; (4) and *Bacillus thuringiensis.* The first two are not yet developed to the point where successful field testing of mass-produced spores has been accomplished and will be discussed only briefly in this paper.

Microsporidia

Wilson, at the Insect Pathology Research Institute, Canadian Forestry Service, is concerned mainly with the activity and effects of microsporidia as they occur naturally in budworm infestations. Means of artificially manipulating microsporidia seem well in the future, although a preliminary small field trial will be attempted in 1975.

Fungi

Entomopthora fungi are being examined by Tyrrell and McLeod at the Insect Pathology Research Institute and by Soper at the University of Maine. Moderately heavy levels of natural infection were recorded recently in a few cases in Ontario and Newfoundland but widespread epizootics are rare. Soper succeeded last winter in mass-producing resting spores on artificial media, but applying the resting spores in the field did not produce infections. The reason for this failure is unknown and should be investigated further. If initial infections can be produced from resting spores, which can be stored, further spread of the epizootic through conidial infections is highly likely. There is no immediate application for controlling spruce budworm, however.

Viruses

Development of viruses is further advanced. Recent progress has been made by Cunningham of the Insect Pathology Research Institute and collaborators with the Great Lakes Forest Research Centre and the Chemical Control Research Institute.

Applications of nuclear polyhedrosis virus (NPV) and entomopox virus (EPV) over the last 4 years were as follows (data from Cunningham):

Year	*Area*	*Virus*	*Size (acres)*
1971	Pembroke, Ontario	NPV	16
	Pembroke, Ontario	EPV	36
1972	Chapleau, Ontario	NPV	640
	Chapleau, Ontario	EPV	1,280
1973	Massey, Ontario	NPV	385
	Aubrey Falls, Ontario	NPV	353
1974	Manitoulin Island, Ontario	NPV	1,295

Carryover infections have been highest with NPV; therefore, later experiments concentrated on that material. An example is seen in annual examinations of the white spruce plantation sprayed in 1971 with NPV. The NPV preparation in that year was contaminated with cytoplasmic polyhedrosis virus (CPV), which explains the presence of these infections (data from Cunningham).

	Level of infection (percent)		
Year	*NPV*	*CPV*	*Fungus*
1971	42	22	–
1972	25	3	–
1973	16	–	17
1974	6	–	23

Initial levels of infection with NPV were high, with lower levels persisting through 4 years. Little foliage protection was achieved in the year of spray; however, some protection occurred in succeeding years, so that after 4 years the sprayed plot appeared in better condition than nearby unsprayed plots.

Experiments with varying the dosage of NPV showed infection rates increased with increasing dosage. But rates of infection have always been considerably greater on white spruce than on balsam fir; infection rates on fir are about one-third of those on spruce. This is believed to be associated with the greater movement and mining of more needles by small larvae on white spruce.

Cunningham makes the following comments regarding the use and future application of NPV:

1. NPV should be used for long-term protection rather than immediate protection, since there is little foliage protection in the year of treatment.

2. Virus is best used in an infestation first reaching moderate to heavy infestation level. A large number of virus-killed larvae are required to heavily contaminate foliage and to ensure high rates of carryover. However, levels of microsporidian parasitism become high in heavier, older infestations and microsporidia inhibit NPV development.

3. Virus research is still at the experimental stage, and there are several problems to solve before it is operational. Formulations might be improved to increase persistence of polyhedra. An efficient ultraviolet screen is required. Virus production requires living insects and is costly. As yet there has been no virus production from tissue-culture methods.

4. Plans for 1975 are to spray 2 to 3 square miles on Manitoulin Island. The insular location may reduce the incidence of moth reinvasion of sprayed plots, allowing a more accurate evaluation of long-term efficacy.

Morris and Armstrong of the Chemical Control Research Institute, along with Howse of Great Lakes Forest Research Centre and Cunningham of Insect Pathology Research Institute, recently reported on efficacy of mixtures of NPV and a conventional insecticide, fenitrothion (.25 oz. per acre). Mortality and foliage protection were good in the year of application, with benefits persisting through a second year. Cunningham believes, however, that the sharp population reductions obtained do not contribute to heavy contamination of foliage with polyhedra; therefore, the method is not suitable for achieving long-term protection with virus.

Bacillus thuringiensis

Bacillus thuringiensis (*B.t.*) has reached a higher stage of development in budworm damage management. Some believe that it is now operational; others believe that some additional development is needed. The material is presently registered in Canada for use under restricted conditions.

Heimpel and Angus, Insect Pathology Research Institute, were largely responsible for the early developmental work with *B.t.* and the spruce budworm. Renewed interest developed 4 to 5 years ago with the development of more effective serotypes of *B.t.* and intensified commercial production.

Smirnoff of the Laurentian Forest Research Centre noted that the addition of the enzyme chitinase to *B.t.* in minute amounts increased efficacy and caused *B.t.* to remain effective at lower temperatures, approaching those that often prevail in early spring in the boreal forest. This was demonstrated in field tests in 1971 and 1972, on 100 and 10,000 acres respectively. Foliage protection with *B.t.* plus chitinase was good, and superior to that achieved with *B.t.* alone. These results were repeated in Maine in 1972 and 1973.

Other trials were run in Ontario during this period by Tripp and Howse, Great Lakes Forest Research Centre, and Morris and others of the Chemical Control Research Institute. They did not use chitinase. *B.t.* in these trials worked well in some cases but not in others. It seemed most reliable where the population was not overly dense and where some stress factor, such as high microsporidian infection, was also present. A high degree of spray atomization, obtained with spinning cage nozzles, also seemed essential.

Questions remained about the necessity for chitinase, and the Chemical Control Research Institute undertook a large experiment in 1973. The two principal products, with and without chitinase, were tested. This involved laboratory tests by Nigam; simulated aerial spray tests on small trees by Hopewell; actual aerial trials by DeBoo, Morris, and Armstrong; and an evaluation of nontarget effects by Buckner and others.

Results of the several studies varied, but the general conclusion was that chitinase appeared to enhance the activity of *B.t.*, apparently causing early gut paralysis and thus increasing foliage protection. This conclusion is not accepted by everyone. It was also concluded that reasonable efficacy could not be expected when prespray populations exceeded 50 larvae per 18-inch branch; too many survivors remained. Specialized application equipment would need to be used to ensure heavy deposit of droplets below 100 microns in diameter. *B.t.* was recommended for use, with chitinase if possible, where these conditions prevailed.

Tests in 1974 over 20,000 acres in Quebec, and on small plots in Maine, tended to confirm these conclusions. There is still some resistance to accepting chitinase as a necessary additive, however, and further evaluation may be justified. The rough experimental designs of field work and difficulty in controlling all conditions have led to conflicting results in several cases.

Where *B.t.* works, it works well. While larval mortality may not be high, foliage protection can be very good. There are nonlethal effects as well, some of which also occur when virus is applied. Larval development is prolonged and surviving pupae and moths are undersized. Sex ratios may be modified to the detriment of females, and some parasitism rates may be enhanced. There has been some evidence of the benefits of *B.t.* treatment persisting through a second year. This has been difficult to prove because of high incidence of moth invasion. The present problem with *B.t.* is cost. Effective rates of 4 to 6 billion international units cost two to three times as much as conventional chemicals, while chitinase remains a scarce and expensive commodity.

B.t. can be considered at present for use in specialized situations, perhaps parks and wildlife refuges, where environmental protection is of prime importance, and costs secondary.

Its more general use is highly desirable because of its lack of toxicity to the human users, to natural enemies of the budworm, and to nontarget organisms in general. But before it can come into widespread use, further research must be done to identify exactly those conditions under which it works or does not work, costs must decline relative to conventional chemicals, and production capacity of *B.t.*, and perhaps of chitinase as well, must be greatly expanded.

Inevitably, some researchers have become interested in testing mixtures of *B.t.* with materials other than chitinase; e.g., conventional insecticides. Hopewell's simulated aerial spray tests showed that one-tenth the operational dosage of fenitrothion, added to *B.t.*, produced good efficacy levels. Laboratory evaluations by Morris, Chemical Control Research Institute, and also in Maine have produced similar results with several insecticides. Field tests in Maine in 1974 with small amounts of Zectran and of fenitrothion added to *B.t.* failed to produce enhancement, but the dosages used were selected with little background data. From 1974 field tests Morris and Armstrong reported considerable enhancement of *B.t.* using Orthene. It is possible that materials such as these insecticides can substitute for chitinase in synergizing *B.t.*.

These additions, small as they are, make an already complex and expensive tank mix even more complex and expensive. In addition, Smirnoff makes the point that the great potential of *B.t.* is the large step in environmental safety that would be taken in replacing conventional broad-spectrum insecticides. Continuing to use small amounts of these as additives would remove some of the luster from that notable accomplishment. *B.t.* requires some additional research before it is truly operational. As mentioned earlier, production costs must decrease and production quantities must increase. In addition, the principal problem is one of application, to ensure that heavy deposits of fine droplets reach the target while emitting small volumes of spray from the aircraft. This will be the object of a 25,000-acre test in Quebec in 1975, and of smaller tests elsewhere.

Summary

In summary, microbials provide no solutions for the total spruce budworm problem in 1975, and probably not even in 1976 or 1977. *B.t.* could rather quickly, however, become an environmentally preferred means of minimizing damage, provided problems of cost, production, and application can be solved. Virus might provide a solution of longer term; however, in this case the remaining problems of production and application are very large.

We cannot gauge the potential of microsporidia and fungi at this point, but they merit extensive investigation.

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arthropod predators and parasitoids

This morning's session is called "Control Methodology Available or Planned for Near Future." If we adhere strictly to that topic I can stop right now, because budworm predators and parasitoids offer no immediate prospects as alternatives to chemical control. But if you want to know whether they have potential in the distant future or whether they have any manipulative significance in current epidemics, I can continue.

There are about 150 species of budworm parasitoids and predators. They probably help regulate budworm numbers at endemic levels when there are only a few thousand in an acre of spruce-fir type, and they continue to be an important influence when budworm populations rise just above the norms of endemic status (100,000 per acre). But in full-blown budworm epidemics (about 5 million per acre) the presence of parasitoids and predators does not seem to influence defoliation. These natural enemies are important, however, for they continue to regulate endemic populations of their alternate and alternative hosts on fir, spruce, and other commerically valuable trees. Without them, we could have multiple epidemics of many pests. Therefore, we must be cautious with spray operations that are as lethal to nontarget insects as to target budworms.

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Classic Biological Control

What is the prospect of introducing foreign parasitoids or predators to strengthen the native complex? I believe it is possible, but a gamble, and certainly not imminent. The Canadian Forestry Service made three unsuccessful attempts to import exotic parasitoids from related budworms: 4 species from British Columbia in the late 1940's; 12 species from Europe in the 1950's; and 2 species from Japan in the early 1970's. The first two efforts were not backed up by data to show why they failed. The latest attempt was a basic commitment to scientific inquiry, confined to insectary studies of attack rate and rearing technology; this attempt was abandoned when host-parasite incompatibility—an encapsulation problem—was demonstrated. An attempt to introduce a gypsy moth chalcid for budworm control in Maine is still in progress.

There are conflicting opinions about the feasibility of introducing one more foreign parasitoid to a native complex that is already 90 species strong. There is nothing inherently impossible about introducing foreign parasitoids to native pests, although we have never had a single success in North American forests. In such attempts we face significant problems in climatic matching, habitat selection behavior, developmental synchronization, behavioral compatibility, host resistance mechanisms, rearing technology, and interspecific competition. Native parasitoids have evolved alongside the budworm for a reasonably stable, live-and-let-live relationship that is not disturbed by occasional budworm epidemics. Foreign parasitoids, on the other hand, are not evolutionarily limited by such homeostatic relationships and they are more likely to come in with a bang or go out with a whimper into extinction.

If there is to be any future in exotic parasitoids, research planning has to be done well. First, we should establish the limiting factors in numerical responses of major native parasitoids to increasing budworm populations. Then our overseas teams should scour the regions of best climatic matching, such as the Sino-Siberian border. Suitable candidates should be investigated thoroughly in prerelease studies. In long-odds gambles we have to maximize the slim prospects of success, and that involves expensive research. The Canadian Forestry Service has no such rational plan at the present time.

Manipulation of Native Parasitoids and Predators

A huge area of spruce-fir forest has only endemic populations of spruce budworm; so there is a risk of still more extensive outbreaks. Some thought has been given to "cooling off" these areas, at least the "hot-spot" epicenters from which epidemics spread. We could use insecticides on these small areas, but we would then risk damaging the restraining biocontrol mechanisms. One line of attack might be to mass-rear native parasitoids for inundative release in epicenters. This might not be too costly if the areas of treatment were small. Dr. Quednau in Quebec has researched the possibility of mass-producing the egg parasite *Trichogramma minutum* Riley for this purpose; perhaps one million per acre might be needed. Because of health problems he abandoned this promising work last year. Other parasitoid species could be factory reared for inundative release, but again a large-scale, expensive, high-risk enterprise is needed. No such proposals are presently under consideration.

Current Chemical Control Operations

Just a brief word on the influence of current chemical control operations on the survival of predators and parasitoids in sprayed areas. The general belief that insecticides are highly damaging to biocontrol mechanisms is a notion derived from agricultural experience with high-dosage recurrent treatments. With a few exceptions, predatory and parasitoid arthropod species populations have not been drastically affected by conventional forest dosages; immediate mortality is often high, but population recuperation appears to be rapid. Ecosystem surveillance, however, is relatively undeveloped and undersupported. There is still a great deal we do not know about faunal community dynamics, and we may yet have to face unpleasant surprises.

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parasites and predators of western spruce budworm

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presented by M. E. McKNIGHT

This topic is presented mainly on the basis of past studies in Oregon and Colorado. Unpublished data from other western areas need to be examined before a comprehensive picture of the role of parasites and predators can be constructed.

For proper perspective, parasitism and predation should be considered in context with life tables. Effects should be related to overall survival within specific age-intervals and to generation survival; yet conventional life tables on spruce budworm may minimize the importance of parasites and predators. In the Pacific Northwest and parts of the northern Rockies, but apparently not in Colorado,[1] a large cumulative mortality—between 80 and 90 percent—occurs between budworm egg deposition and the start of bud-feeding the following spring. A practical analytical approach would be to begin the life table with the bud-feeding population since this is the population component which causes damage. However, to compromise, let's explore the role of parasites and predators

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[1] Because the egg stage and bud-feeding larvae are distributed differently on the whole branch, the 24-inch branch sample may have underestimated this mortality.

by dividing the life table into a prefeeding segment and a feeding-to-flight segment.

Prefeeding Age-Intervals

Egg Stage

In this first age-interval, budworm populations suffer only a small percentage reduction (although substantial numerically) from parasites, predators, and other factors. In increasing infestations in Oregon, this amounts to about 12 percent. Parasitism by a tiny chalcid, *Trichogramma minutum* Riley, causes about one-half of this reduction; parasitism is higher in the upper crown. Predation, indicated by feeding punctures and boring holes, amounts to about 2 percent. A variety of predators appear involved, including a large mite. Neither the total egg mortality nor the sum of parasitism and predation shows a relationship to generation survival.

First Instar to Early Third Instar

Fall and spring dispersal of larvae is considered, by analogy with the eastern budworm, to be the main mortality factor during this age-interval. It probably is quite important; however, studies in Oregon show the occurrence of considerable predation in late summer and early fall. The major predators are larvae of a small clerid beetle and a snake fly. Apparent mortality was close to 30 percent in a light infestation and 20 percent in a heavy infestation. We have no idea how much this predation can vary from place to place and between years. Because budworm mortality for this age-interval is difficult to measure with much precision, it is difficult to put this predation in proper perspective.

Feeding-to-Flight Age-Intervals

Third Instar through Fifth Instar

Hymenopterous parasites originating from attacks on budworm larvae the previous fall develop, kill their hosts, and form easy-to-recognize cocoons. Two of these, *Apanteles fumiferanae* Viereck, and one or more species of *Horogenes,* kill their hosts about the time nonparasitized larvae are entering the sixth instar. Larvae containing these parasites are stunted and usually misidentified as to instar. Their elimination from the population causes an apparent acceleration in budworm development. A third species, *Glypta fumiferanae* (Viereck), commences to kill its hosts shortly thereafter but the process is often extended until the onset of budworm pupation.

These species attract considerable attention from biocontrol students. However, eastern Oregon data show that after 3 years of increasing budworm infestation the combined parasitism by these species reaches a plateau, somewhere between 30- and 40-percent parasitism, and stays there. In a similar vein, McKnight's study in Colorado showed that parasitism was about the same for increasing and decreasing infestations. Thus, the effectiveness of this group of species is not indicative of budworm trends.

Sixth Instar

A more flexible and unpredictable group of parasites attack the last-instar budworm. Component species vary somewhat and effectiveness can vary considerably over the western region. In western Oregon, not considered typical budworm country, an externally feeding hymenopteron, *Phytodretus fumiferanae* Rohwer, and a tachinid, *Lypha fumipennis* Brooks, are quite effective in killing mature larvae; however, we have no life table data for this area. *Phytodretus* is common but of minor effectiveness in eastern Oregon and parts of the Rocky Mountains. In eastern Oregon and Washington, and parts of the Rockies, particularly Colorado, several tachinids attack the budworm. The most important species are *Madremyia saundersii* (Williston), *Ceromasia auricaudata* Townsend, and *Omotoma fumiferanae* (Tothill). Except for *Omotoma,* adults of these tachinids emerge in late summer and must find an alternate host for the winter. At times, in Oregon, this complex has caused an apparent parasitism as high as 45 percent. In Colorado, McKnight found parasitism to be somewhat higher in increasing populations; this also appears to be the case in Oregon. McKnight states that real mortality in this age-interval was four times higher in increasing populations. In our sampling we are probably underestimating the effect of this group of parasites, because of problems in timing the sampling. We may also be overlooking the effects of some small external parasites, such as *Bracon poliventris* (Cushman), which often show up in decreasing populations, particularly in sprayed areas.

Pupae

McKnight and I restrict the biotic factors in this age-interval to agents attacking and killing pupae, and ignore carryover effects of tachinids already recorded from rearing of mature larvae. Common parasites include a sarcophagid, *Agria housei* Shewell, three or more ichneumonids, and some chalcidoids which are mostly secondary. Some minor predation is caused by birds and larvae of a couple of normally phytophagous lepidopterons. Mortality caused by these agents is higher in decreasing populations, and normally indicative of previous strong population reductions.

Summary

The most useful estimates of parasitism and predation are those related to predicting the size of the new budworm brood. Estimates for the fourth-instar age-interval would be helpful in evaluation; thereby providing a prelude to the egg surveys. This requires sampling and rearing mature larvae—timed with 30- to 40-percent pupation, and treating pupae as larvae. For simple analysis, the budworm density and parasitism at this stage should be related to density of initial bud-feeding populations.

Any estimates of parasitism should be tied in with estimates of population density. Otherwise, the information is of no real value in predicting budworm trends and survival.

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silvicultural control techniques for the spruce budworm

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One-half century ago, the use of management techniques was proposed as the ultimate solution for handling the spruce budworm problem in aging spruce-fir forests.

The recommended management control techniques were based upon retrospective analyses of spruce budworm outbreaks. Observers had deduced that the most vulnerable stands were the ones most damaged and, therefore, that characteristics of these stands helped identify which stand factors were important (Morris, 1958). They concluded that managers could minimize the impact of outbreaks by preventing them or by reducing their frequency or severity. To do so, some suggested techniques were:

1. Shorten rotation age to less than 50 years and promote vigorous stands on better soils (Swaine et al., 1924).
2. Make partial cuttings on short (15-20 year) cutting cycles (Westveld, 1946).
3. Break up susceptible cover types into small areas separated by nonsusceptible types (Graham and Orr, 1940).

4. Maintain mixed species composition (Swaine et al., 1924; Turner, 1952).

5. Identify overmature and high-volume stands and accelerate cutting on such stands (Morris and Bishop, 1951; Balch, 1946).

6. Prevent stands from reaching maturity simultaneously over large contiguous areas (Morris, 1958).

7. Clearcut on a 50-year rotation (Hatcher, 1960).

8. Presalvage areas identified as vulnerable (Blais, 1964).

9. Develop road systems to permit flexibility in adjusting harvesting schedules (Morris, 1958).

Conditions That Affect Budworm

Stand Density Affects Larval Survival

Open stands are conducive to large-larvae survival (because of the increased crown exposure) and high stand density is conducive to survival of small larvae (because of the reduced waste of dispersing first- and second-instar larvae). It has been postulated that maximum generation survival occurs in conditions where the product of large-larvae survival and small-lavae survival is maximum. These conditions are represented by mature fir stands having well-developed lateral crown exposure without a large component of nonhost species or of large unstocked openings (Mott,1963). Exposure affects radiation intensity; thus, it affects body temperature of budworm larvae (Shepherd, 1958).

Stand Composition Affects Damage

A high mixture of spruce with balsam fir resulted in increased damage to the fir; where the host species were intermediate in the overstory, percent mortality of fir decreased as the proportion of hardwoods increased (Turner, 1952; Batzer, 1969). Where birch dieback removed the hardwood overstory, the damage to balsam fir was severe (Hatcher, 1963).

Black spruce is damaged less severely than balsam fir because buds break dormancy after budworms emerge in the spring (Blais, 1957). However, severe damage to understory balsam fir can result in clearcuts where residual spruce harbor high, overwintering larval populations because most emerging larvae disperse to the understory. This causes severe damage to the advance regeneration. Such damage may be prevented by (1) felling residual balsam fir and spruce in cutover stands having established balsam fir regeneration, and (2) felling all host trees (even those not utilized) when harvesting stands where the next crop will be provided by balsam fir advance regeneration (Batzer, 1968).

Pure white spruce may sustain persistent infestations without appreciable mortality even though white spruce has more foliage than balsam fir. However, if severe defoliation of white spruce occurs, it may succumb to bark beetle attack (Greenbank, 1963b). In the East, balsam fir is first on the damage scale, white spruce second. In the West, grand fir is first and Engelmann spruce is intermediate, while Douglas-fir and ponderosa pine are last (Williams, 1966).

Weather Affects Budworm Dispersion

Stands downwind may be invaded by moths and small dispersing larvae (Mott, 1963). In eastern North America, stands along the western edge of a heavy infestation or isolated stands are less likely to become severely damaged. Perhaps the effects of mountainous terrain on airflow influence dispersion of larvae and moths. Cloud-free zones may be identified from weather records to delineate high-hazard areas with potential for outbreaks (Wellington, 1965). High evaporation rates are characteristic of outbreak areas of the 2-year cycle budworm in western Canada (Shepherd, 1959). Spruce budworm populations increase with successive years of dry and sunny weather. The production of male flowers also follows this pattern. However, it is now thought that the key to the maturity aspect is not male flower production, but rather stand microclimate. It still is not clear how male flower production is affected during periods when budworm populations are endemic (Greenbank, 1963a).

Results of Experimental Cuttings

Recommendations developed from trials of cutting methods made in Quebec, Maine, New Hampshire, and Minnesota suggest the following:

1. Partial cutting in mature stands in Quebec resulted in excessive mortality attributed to damage by wind. In stands under 50 years old and in uneven-aged stands, removal of less than 40 percent of the total basal area resulted in acceptable postcut losses during the first 5 years after cutting (Hatcher, 1961).

2. Partial cutting in Maine and New Hampshire indicated that cuts in spruce-fir stands should not be more than 25 percent of the basal area because of the increased risk of wind damage (McLintock, 1954).

3. Although clearcutting in Quebec produced rapid and satisfactory restocking, the high proportion of balsam fir in the new stands rendered them highly susceptible to spruce budworm in the future (Hatcher, 1960).

4. A replicated pilot study in Minnesota indicated that defoliation intensity per square foot of basal area decreased as cutting intensity increased. In this study, commercial clearcutting (approximately 75 percent of the original basal area was removed) and partial cutting (30 percent of the basal area in host trees was removed) were tested (Batzer, 1967).

Some Potential but Untested Management Practices

Forest fires have delayed invasion of other types by balsam fir (Blais, 1968); thus, increasing acceptance of prescribed burning makes it an important silvicultural tool in retarding natural succession to the mature spruce-fir forest.

Because of the increasing demand for pulpwood and the acceleration in the practice of planting after mechanized harvesting, it may be possible to manipulate the forest by replacing susceptible species with less susceptible ones (Blais, 1973).

Disadvantages of Silvicultural Control

It is difficult to test silvicultural techniques because of the dispersal abilities of the budworm. Several hundred square miles can be severely damaged as a result of population pressure from favorable areas, regardless of whether or not they represent susceptible conditions (Morris, 1963). Furthermore, it is not possible to predict outbreaks on the basis of past records (Blais, 1965).

Most silvicultural theories that have been proposed to minimize the impact of insect outbreaks have not been put into practice on a scale large enough to test their effectiveness against epidemic populations (Frank and Bjorkblom, 1973).

Management of the forests of northern New Brunswick in the past 25 years has not reduced their susceptibility to attack (Van Raalte, 1972).

Advantages of Silvicultural Control

Any technique aimed at prevention of outbreaks has the advantage of self-perpetuation; hence, it may be the cheapest in the long run (Morris, 1963).

Some degree of resistance to damage (susceptibility and/or vulnerability) may be achieved as a result of normal harvesting operations at no extra cost or at only slight increases in cost.

Environmental contamination by chemicals may be reduced.

Conclusions

Efforts to produce resistant forests of more diversified age-classes will more likely succeed as the areas under management become larger (Prebble and Morris, 1951). However, there still is not sufficient information to evaluate the effectiveness of silvicultural techniques for spruce budworm control. Statistically sound studies based on reliable data are needed so that this approach can be evaluated wherever the spruce budworm is a problem.

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forest practices, silvicultural prescriptions, and the western spruce budworm

I appreciate the invitation by Dr. Batzer and Dr. McKnight to discuss forest practices, silvicultural methods, and the western spruce budworm, *Choristoneura occidentalis* Freeman, on this panel concerned with control methodology available or planned for the near future.

I will briefly mention three aspects of the situation: (1) past research in the West, (2) problems and needs of resource managers in the northern Rockies, and (3) research underway in western Montana.

Past Research

I know of only three published papers concerned with forestry practices or stand conditions and the spruce budworm in the West. Following a study of stand condition and spruce budworm damage in a western Montana forest, Fauss and Pierce (1969) concluded that preventing a buildup of budworm populations through silviculture would require either reduction of the Douglas-fir stocking to a very low level or a change in the stand composition to favor pine. On farm woodlots or other land where precommercial thinning is practiced, they indicated that ponderosa pine probably should be

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favored over Douglas-fir or should constitute at least 50 percent of the residual stand if the risk of spruce budworm defoliation is to be reduced.

Williams and Shea (1971) discuss two silvicultural practices that could render the forest environment less vulnerable to buildups of budworm populations: (1) reducing the true-fir complement in all budworm-populated stands, and (2) cutting Douglas-fir and burning the cutting units to favor ponderosa pine over all firs. They generally recommend patch clearcutting, with the cutting units kept as small as practicable. In a related study, Williams and others (1971) add a third practice—maintaining a stand of thrifty, rapidly growing trees.

These appear to be sound recommendations that should be tested. However, many of the budworm-infested forests in the northern Rockies are not in the pine-fir type but are considered to be in the larch-fir type, composed essentially of western larch, Douglas-fir, Engelmann spruce, and subalpine fir. Because the western spruce budworm thrives on all of these hosts, some of the current recommendations may not be applicable.

Management Problems

The three most serious resource management problems in areas infested by the western spruce budworm are: failure of many stands to regenerate; lack of seed for regeneration programs; and impacts from growth loss and tree deformity. On some national forests, budworm larvae feeding on seedlings have contributed to regeneration failures in shelterwood and seed-tree cuttings.

In western Montana and northern Idaho, damage to seedlings appears to be more severe in naturally regenerated areas after partial cutting than in clearcuts, particularly in the larger clearcuts. Other cutover areas have not regenerated, either because no cones have been produced on heavily defoliated trees or because cones have been destroyed by budworm larvae. Some national forests have been unable to collect seed from budworm-infested areas since 1967, a fact that may require a change in management plans.[1] These seed shortages make it difficult for forest personnel to collect seed for reforestation according to habitat type and elevational zones. A new Regional directive requires seed to be planted near the site from which it was collected.[2]

[1] Memorandum from the Region 1 Regional Forester, Steve Yurich, to forest supervisors dated May 1, 1973, including minutes of western spruce budworm workshop held in Missoula, Montana, on March 29, 1973.

[2] Memorandum from Jerald Dewey to William Ciesla dated October 18, 1972, concerning an ad hoc spruce budworm committee meeting in St. Maries, Idaho, on October 6, 1972, to evaluate the spruce budworm situation.

Resource managers on several national forests in western Montana and northern Idaho are asking for guidance in managing budworm-infested stands, particularly young stands. In addition to the judicious use of insecticides, managers are interested in the consequences of thinning, the types of cutting—clearcutting, shelterwood, seed tree, etc.—that should be used, the species (if any) that can or should be favored, and so on. A concentrated research effort could provide guidance.

Current Research

The Intermountain Forest and Range Experiment Station has three studies underway that are concerned with the relationships between harvesting practices, silvicultural treatments, or both, and the western spruce budworm.

In 1962 we discovered that budworm larvae actually sever the stems of terminal and lateral shoots of western larch, in addition to feeding on the foliage (Fellin and Schmidt, 1967).

In 1965 a study was designed to determine: (1) the effect of this type of budworm damage on height growth and form of young western larch, and (2) if spacing of the trees has any effect on the amount of intensity of budworm damage to trees.

We found that this budworm larval feeding jeopardizes straight form and rapid juvenile height growth of trees by producing crooked and misshapen trees (Fellin and Schmidt, 1973), resulting in a net loss in height growth of 24 to 30 percent (Schmidt and Fellin, 1973).

We also found that the incidence of budworm damage was not consistently related to stand density. In the first year of the study, when budworm damage was relatively light, the percentage of dominant trees with leader severances was highest in the plots having the fewest trees. However, this relationship was not apparent during the succeeding years as the overall level of budworm damage increased.

A second study was initiated in 1968 to determine if the application of nitrogen, phosphorus, or potassium fertilizers in six different treatment combinations applied to western larch regeneration had any effect on the abundance of, or damage by, spruce budworm larvae.

Measurements were made of fascicles and lateral shoots damaged by budworm larvae in 1968, 1970, and 1972. Data analysis is incomplete, but it appears that in most of the study areas the incidence of damage was greater on trees in fertilized plots than in the controls. Particularly among the fertilized plots, the data indicate there was less damage where nitrogen was not applied. At this time data on larval abundance are not available.

The most elaborate and recent of the three studies is a cooperative effort with the Northern Region of the Forest Service involving a comprehensive study of timber harvesting systems in the northern Rockies. The study is located on the Coram Experimental Forest near Glacier-Waterton International Peace Park in northwestern Montana. Most of the experimental forest is infested with the western spruce budworm.

The study has two basic objectives: (1) evaluate skyline logging systems and intensive timber utilization under shelterwood, group selection, and clearcut silvicultural prescriptions in larch–Douglas-fir stands; and (2) evaluate the biological and environmental effects of harvesting and degree of residue utilization. The latter objective includes influences on revegetation and stand re-establishment; soil, water, and nutrient regimens; insect and disease problems; forest aesthetics; and postharvest management activities and costs.

Within each of the three cutting units, three silvicultural prescriptions will be applied with and without prescribed fire:

1. Cutting and removing all understory, including broad leaves, with no burning.

2. Cutting and leaving all understory, including broad leaves, with burning.

3. Removal of all or part of the merchantable overstory, with minimum damage to the residual understory, and no burning.

The cutting, yarding, and removal of the merchantable and nonmerchantable material from the forest took place during 1974. The prescribed burning will be done in the fall of 1975, followed by the various posttreatment measurements.

This study involves some 28 principal investigators in nine biological and five nonbiological fields. One of the biological studies will evaluate the combined effects of harvesting methods, silvicultural prescriptions (especially fire), and residue treatments on the impact of the western spruce budworm, particularly as the budworm affects newly established stands, residual understory and residual overstory, and production of cones and seeds.

Some of our first pretreatment efforts have been to measure dispersal of second-instar larvae, defoliation, and top kill in undisturbed stands. Following treatments and burning, we will begin to measure the newly regenerating stand, and we will also compare the relative incidence of damage on planted trees with trees developing from direct seeding. We will continue to follow the impacts of the budworm in the study area as the infestation ages.

We believe these research efforts will provide some guidance for resource managers and also will contribute to our continuing effort to coexist with the western spruce budworm in the northern Rocky Mountains.

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status of pheromones for western spruce budworm

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presented by CHRIS J. SANDERS

Trans-11-tetradecenyl aldehyde has been identified as a major chemical component of the western spruce budworm, *Choristoneura occidentalis* Freeman. A close relative of the western budworm, *C. viridis* Free., or the Modoc spruce budworm, responds to a slightly different compound, *trans*-11-tetradecenyl acetate. These identifications were derived through co-operative research with the Canadian Forestry Service at Sault Ste. Marie, Ontario. The identification effort is continuing with the objective of determining the structure of possible secondary compounds that could enhance the potency of the pheromones.

These materials have been synthesized and formulated in controlled-release systems for use in trapping programs. The trapping studies are aimed at the development of survey systems for population sampling and damage prediction. Similar research is being conducted by the Canadian Forestry Service in British Columbia. In the western United States, a co-operative effort is underway in the U.S. Forest Service. Major contributors include the Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon; Pacific Northwest Region, Portland, Oregon; and the Intermountain Region, Ogden, Utah.

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sex attractants and growth regulators

Insect Growth Regulators

Laboratory investigations by I. Outram of the Maritimes Forest Research Centre, Fredericton, and A. Retnakaran of the Insect Pathology Research Institute, Sault Ste. Marie, have demonstrated that insect growth regulators (juvenile hormones, juvenile-hormone analogs, and juvenile-hormone mimics) have ovicidal effects and cause death or growth abnormalities when applied to larvae or pupae. The most susceptible stage is the sixth instar, and results have been sufficiently encouraging to warrant field testing.

In 1973, the Maritimes Forest Research Centre in cooperation with Ciba-Geigy tested two compounds, each applied by helicopter on 400-acre plots at 1 + 1 oz. per acre and 2 + 2 oz. per acre. Up to and including the adult stage, results showed 41 percent of the population was affected at the higher dosage of one compound.

In 1974, the Insect Pathology Research Institute conducted a trial involving several compounds and mixtures each applied by Agcat to 100-acre plots. Treatments were as follow:

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Treatment	*Dosage per acre*
Juvenile-hormone analog (Hoffman-LaRoche)	5 oz. 3 oz.
Juvenile-hormone analog (Zoëcon)	5 oz. 3 oz.
Inhibitor of chitin synthesis (Philips-Duphar)	5 oz.
B.t. (Thuricide)	6 BIU 3 BIU
Zoëcon + *B.t.*	3 oz. + 3 BIU

Only the compound inhibiting chitin synthesis showed a significant effect.

In view of the promising laboratory tests and the results obtained from the application of insect growth regulators on hemlock looper, these results were disappointing; obviously further research is required, and we cannot expect insect growth regulators to be in operational use for several years.

Sex Attractants

Sex attractants, compounds mimicking females by attracting males, are known for four of the five budworms feeding on spruce-fir. *Choristoneura fumiferana* (Clemens), *C. occidentalis* Freeman, and *C. biennis* Free. are all attracted to *trans*-11-tetradecenal; *C. viridis* Free. to *trans*-11-tetradecenyl acetate. Both compounds are commercially available. The sex pheromone communication system of *C. fumiferana* definitely contains one or more secondary compounds, and it is probable that secondary compounds occur in the other species, making the pheromones more species-specific. The correct "blend" is essential for optimum attraction, and work on the identification of these compounds is under way. However, the *cis*-isomer has a synergistic effect on male *C. fumiferana,* and a mixture of 99 *trans*:1 *cis*, in a solid plastic form gives good catches, adequate for survey monitoring in low-density populations.

Four types of trap are commercially available. Their relative effectiveness in high and moderate population densities of *C. fumiferana* is shown in Table 1. Their effectiveness in low population densities and their ability to withstand exposure for use as a "once-a-year" trap are currently under investigation.

Table 1. Number of male *C. fumiferana* (Clemens) trapped in 3M- and Zoëcon-brand traps baited with *trans*-11-tetradecenal or left empty as checks in high and moderate population densities

Population density and trap use	Traps						
	3M Sectar 1[1]	3M Sectar 1 (folded)	3M Sectar 1 (unfolded)	3M XC-26	3M XC-26[1]	Zoëcon C[1]	Zoëcon CP[1]
High population							
Baited	57.4±4.9				72.0±5.0	108.8±5.3	73.2±6.8
Check	27.2±4.9				10.2±2.5	61.0±7.0	42.5±4.1
Moderate population							
Baited	–	16.8±5.4	15.3±1.4	21.8±4.9	28.2±0.9	56.4±11.4	28.6±6.4
Check	–				0.4±0.4	12.3± 1.9	2.4±1.0

[1] Number of male *C. fumiferana* in this column with ±1 standard error.

The presence of *trans*-11-tetradecenal in the atmosphere disrupts the ability of male *C. fumiferana* to find a female (Table 2). One of two known inhibitors, *trans*-11-tetradecenyl acetate, however, has so far failed to disrupt behavior; the other, the equivalent alcohol, is under investigation. *Trans*-11-tetradecenal has been encapsulated, in similar fashion to disparlure (Cameron and Schwalbe, 1974), and information on the release rate of this compound is currently being gathered in preparation for field trials from a helicopter in 1975. Disruption of mating behavior will probably be most effective at low population densities. It may be of use in dampening incipient population increases; but in any event, operational use is still several years away.

Table 2. Daily catches of male *C. fumiferana* (Clemens) by virgin females set out in a 3 x 3 grid, with 20 m. between traps. Shows effect of surrounding center trap with *trans*-11-tetradecenal or *trans*-11-tetradecenyl acetate by placing plastic formulation of compounds at eight cardinal compass points on 10-m. radius. Same female left in trap for days 1 through 4, another for days 5 through 8

Traps	Day							
	1	2	3	4	5	6	7	8
Plot 1								
Untreated[1]	23.4	[2]1.0	28.9	34.2	29.3	[3]48.7	74.7	85.8
Treated	15	0	16	15	5	61	68	76

Table 2, continued

Traps	Day							
	1	2	3	4	5	6	7	8
Plot 2								
Untreated[1]	24.9	[3]22.2	24.2	33.8	72.0	46.2	[3]70.0	90.0
Treated	25	7	16	15	39	35	31	56
Plot 3								
Untreated[1]	18.9	23.8	[2]8.9	29.8	67.2	[2]50.9	63.1	101.1
Treated	28	8	0	16	85	8	48	68
Plot 4								
Untreated[1]	21.0	8.9	[3]18.4	17.7	63.1	37.6	[2]48.6	123.0
Treated	3	26	126	10	62	80	2	51

[1] Average of eight traps.

[2] *Trans*-11-tetradecenal.

[3] *Trans*-11-tetradecenyl acetate.

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unconventional chemicals

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Besides the insecticides already described, we should consider what may be called "unconventional chemicals," such as attractants, juvenile hormones, and feeding deterrents. These chemicals are a mixed bag of underexploited but potentially useful materials for insect suppression. Only limited attention is being given to developing these promising materials for suppression of the spruce budworm; a much larger research effort seems justified. The limited research on these unconventional chemicals is probably due in part to the costly and elaborate test procedures generally necessary to evaluate their diverse effects and to the fact that conventional insecticides in comparison offer a quicker solution.

These miscellaneous materials can be divided into two groups: (1) chemical determinants of behavior (behavioral chemicals)—e.g., attractants (including pheromones), repellents, feeding deterrents; and (2) insect growth regulators—e.g., insect hormone mimics, antimetabolites.

Research on chemical determinants of behavior for the spruce budworm in the United States is restricted to studies on pheromones being conducted by Dr. Gary Daterman of the Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon. The principal component of the western spruce budworm pheromone mix was indentified in collaboration with Canadian scientists. Co-operative studies are now underway to evaluate the potential of this material as a survey tool. Second-instar larvae are sampled yearly from study plots and correlated with adult moth populations estimated from catches in pheromone traps. Plans are being made to eventually include measurements of defoliation, so that correlation with population levels will yield reliable predictions of damage potential.

No research is now underway on the use of pheromones for control of spruce budworm in the United States. An approach that has already shown promise in agricultural pest control and elsewhere is the use of pheromones to disrupt mating. Another promising approach is to team pheromones with limited insecticidal applications.

Research on insect growth regulators is also far below the level warranted for these promising materials. The bulk of the research in spruce budworm control in the United States is being conducted by the Insecticide Evaluation Project. Research so far is laboratory oriented, and no field tests of insect growth regulators against the spruce budworm have yet been made.

These materials can be grouped into three classes: insect hormone mimics; the compound TH-6040; and plant derivatives or extracts. Insect hormone mimics represent the largest share of our research. Most of them are mimics of the insect's natural juvenile hormone. Each compound is evaluated by incorporating it in artificial diets to determine its feeding activity; the compound is also tested by applying it as a spray to determine contact activity. In addition we are beginning studies using potted Douglas-fir trees to determine the residual life of hormone mimic sprays after they are applied to trees and the foliage deposits are weathered and aged.

Effects on the insect are evaluated in several ways, including observations on acute toxicity, on abnormalities in morphological development, on the mating process, and on fertility. Most of the abnormalities occur at the larval/pupal molt. The tests are generally conducted on the sixth instar, since the action of juvenile hormone mimics is usually most pronounced at the larval/pupal molt. Tests on earlier instars are beginning but have not proceeded far enough to permit even speculation.

We have evaluated about 16 compounds so far. Of these 16, the most active are four Zoëcon products: Altozar (ZR-512), Altosid (ZR-515), ZR-619, and ZR-777. Each one is highly effective at about 0.2 p.p.m. in diet feeding tests and at about 5 oz. per acre in spray chamber tests.

The second group of insect growth regulators is represented by the compound TH-6040, the only material of this type we have tested so far. It is a substitute urea developed by Philips-Duphar of The Netherlands. It has a good safety profile for the major group of invertebrates and is highly selective on arthropods and even between insect taxonomic groups. This material acts by interfering with chitin synthesis and causing fatally abnormal molts.

Results to date show that the LC_{50} of the TH-6040 is about 1 p.p.m. for third and fourth instars of the western spruce budworm and 20 p.p.m. for sixth instars. It is highly toxic, with much higher activity against the earlier instars. Its activity on the Douglas-fir tussock moth demonstrates its selective nature. Against this insect, the LC_{50} is 0.04 p.p.m. on second instars and 0.1 p.p.m. on fifth instars. The differential results, by instar, are not nearly as pronounced as those for the budworm.

TH-6040 is also highly active against the gypsy moth. Field tests on this insect and the Douglas-fir tussock moth have demonstrated that TH-6040 has considerable activity in the field as well as in the laboratory.

The third group of insect growth regulators we have tested are the plant extracts. We have been co-operating with Drs. Leonard Jurd and Roy Teranishi of the Agricultural Research Service, Western Regional Laboratory, Albany, California. These scientists are studying structure-activity relationships of plant extracts by derivatizing active molecules to increase biological effects on insects.

We began bioassays in 1974. So far we have examined nine compounds for acute toxic, morphogenetic, and fertility effects. With one minor exception, no significant leads have yet developed from this work. From the pragmatic standpoint, we consider these materials mainly as research curiosities and their development for operational use a long way off.

In summing up, both the chemical determinants of behavior and the insect growth regulators seem to warrant far more research and development than they now receive. They have excellent potential as effective agents for insect suppression, with the added advantage of a high level of environmental safety. Right now, however, the stage of development for most of these materials is far removed from operational use in forest insect suppression. The development of TH-6040 appears to be the most advanced. If laboratory and field research and development were accelerated, this compound could be registered for use in 2 to 4 years.

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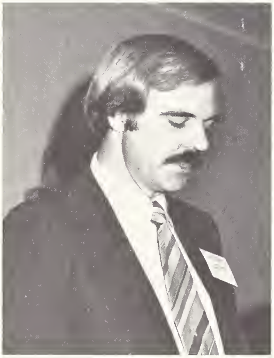
integrated pest management systems for spruce budworm



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A definition of integrated control in its narrowest sense would be "applied pest control that combines and integrates biological and chemical measures into a single unified pest control program." This definition is fine except that it is based on only a two-component system, biological and chemical control. More recent definitions have one common theme: The system must be based on sound ecological principles. A better definition might be "an ecological approach to pest management in which all available necessary techniques are consolidated into a unified program, so that populations can be managed in such a manner that economic damage is avoided and adverse side effects are minimized."

This last definition implies several things: First, that we have a good understanding of pest populations, stand dynamics, economics of our system, and biological side effects of treatments; second, that we are committed to using an integrated system approach in the face of sociopolitical pressures that encourage easy, but not necessarily ecologically acceptable, actions.

Luckily in forestry we are not at the point where our tolerance for many insect pests is at or near zero; thus eradication with its attendant problems is not one of our goals. For most phytophagous pests, and especially spruce budworm, some defoliation is tolerable and economic damage may not occur until several years have passed. This increases the chance for natural enemies or abiotic factors to suppress the outbreak and it also gives us more time to analyze the ecologic and economic situation and to plan our management strategies accordingly.

The first consideration in an integrated pest management system is a good understanding of the pest population as well as its role in the ecosystem. Figure 1 shows population trends in an outbreak cycle. If an economic threshold is drawn at 5 on the y axis then one alternative becomes obvious—some stands do not need treatment to prevent economic damage even though the population may be cycling at higher than normal levels.

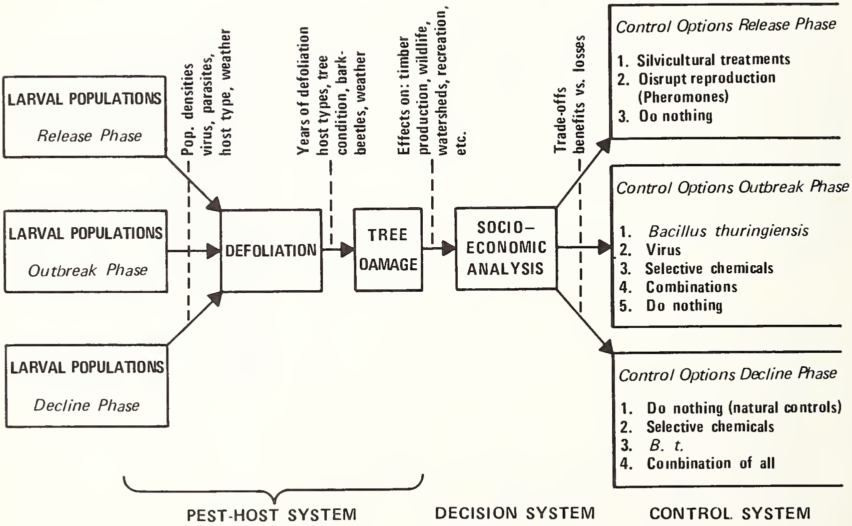
FIGURE 1.

Population trends (N_L) in non-outbreak stands: G4 — Mature plot, G5 — Immature plot; and in outbreak stands: K1 — Mature plot, K2 — Immature plot. (from R. F. Morris (ed.), The dynamics of epidemic spruce budworm populations. Entomol. Soc. Can. Mem. 31, Figure 28.1)

Of course, identifying the economic threshold is the rub. How we determine and set this level is critical to the entire concept of integrated pest management. We must know how much defoliation is caused by various population levels in the various population phases, what effect this defoliation has on the tree, and what effect different levels of tree damage have on net productivity of various types of stands. In short, we need an understanding of all the effects (and they are not all negative) spruce budworm has on stand dynamics. Then we can translate tree damage and stand disruption into a whole set of economic values; namely, effects of stand damage on timber production, recreation, wildlife, watershed, etc. With this bank of biologic and ecologic data—and it is a considerable amount of information—we can start examining our treatment options and determine a management strategy. This, or course, implies that we have a bag full of tested and safe, biological, chemical, cultural, or other treatments available. Figure 2 illustrates diagrammatically the flow of steps leading to final treatment in an integrated pest management system. The integration part is our dedication to considering all pertinent biologic and economic factors along the way and our final selection of ecologically sound treatment alternatives. Notice that a "do nothing" strategy toward the infestation may always be a viable alternative on economic or ecologic grounds.

FIGURE 2.

Integrated pest management system for the future.

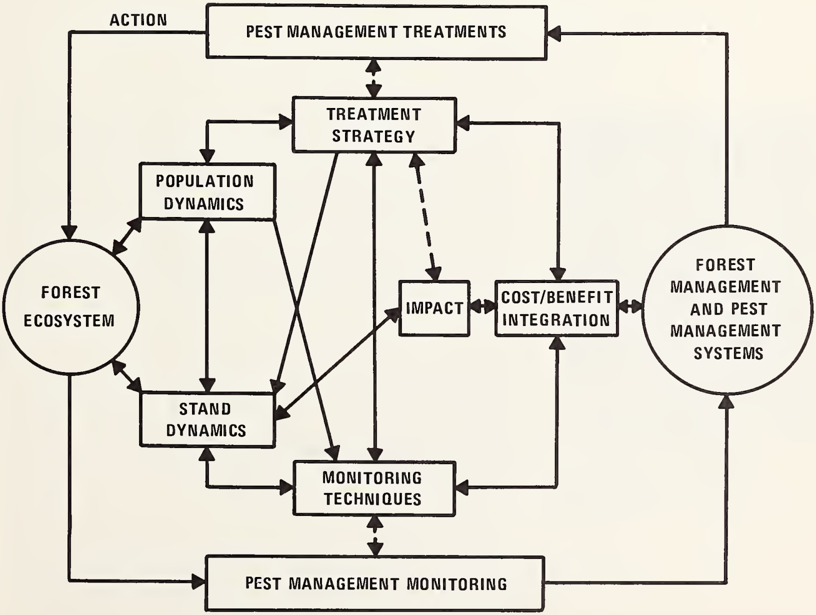


Some of you may be thinking that this approach is pretty far out and maybe some time in the future we will be attacking our pest problems in this manner. Anyone who has put together an Environmental Impact Statement knows that this is the type of information and analysis required by law. We are just doing a more or less acceptable job depending on our data base, understanding, and desire to conform to the spirit of pest management principles.

This panel is looking at control methodology planned for the near future. It is obviously going to take a concerted research and development effort to acquire the information and understanding necessary to apply integrated pest management systems. Such a program for western spruce budworm was submitted to the Washington Office 2 years ago; it needs revision and then must be funded at a high level for at least 5 years. The system is complex, as Figure 3 illustrates. It will require an emphasis on models and systems analysis. Hopefully this approach will provide the analytical framework and the mathematical and statistical techniques required for decision making in complex spruce budworm systems.

FIGURE 3.

Decision-making process for integrated forest pest management system. (from Western Pine Beetle IPM Program).



IV

Environmental, Operational, and Economic Considerations in Suppression Programs

The individual presentations by panel members contain many items of significance to the spruce budworm problem. From these we have drawn the following points for specific comment and have prepared recommendations related to them. Eastern budworm was discussed more than western budworm because the members of the panel are primarily from the eastern region of the United States and Canada. Our recommendations are intended to summarize, strengthen, and increase the amount of effort on both the eastern and western species.

1. The overall spruce budworm problem in the eastern United States and Canada needs further review. The data that are already recorded should be retrieved and analyzed with a long-term view in mind. Not enough attention has been paid to the information already available on the impact of this insect, though some efforts have already been made.

   Recommendations
   Review the data on past outbreaks in Maine and eastern Canada. Relate this information to present conditions and develop long-term predictions related to various strategies.

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2. The presentation by Great Northern Paper Company provided a useful predictive model of budworm effects on fiber supply in one portion of the outbreak and raised fears about the company's ability to maintain production in the future. These data could be further developed in relation to the economic impact on the people of the region and State.

   Recommendations
   Bring together similar information on all spruce-fir types in Maine and develop economic data on the long-range economic effects of an outbreak of the magnitude of the earlier one.

3. Careful monitoring is a vital part of any spray operation. Data should be available on all aspects of the areas treated and the organisms that are present.

   Recommendations
   A specified percentage of project funds should be set aside specifically for monitoring control projects. This is generally done but possibly not thoroughly enough in some cases. Monitoring should be carried out for both organisms and chemicals.

4. The importance of carefully prepared and thorough benefit-cost analyses cannot be overemphasized. The methods are available and should be utilized.

   Recommendations
   All projects should involve a careful benefit-cost analysis, and long-term studies should include people trained in these techniques.

5. Congress now requires many different pieces of information on all projects, including both economic and sociological information as well as reports on environmental impacts. All involved with projects should be thoroughly aware of registration problems and rules set down by the Federal Insecticide, Fungicide, and Rodenticide Act, as amended.

   Recommendations
   Care should be taken to comply with all Federal requirements on projects. Close co-operation should be maintained with Canadian efforts on insecticide development to avoid duplication. Further informative co-operative efforts between the United States and Canada should be encouraged by all agencies of both governments, using both co-operative teams of individuals and assistance in funding where necessary to complete priority work.

6. Research on other organisms either associated with or causing deterioration before or after budworm infestations has not received much attention. Perhaps much more could be done through effective management to reduce some of the attendant problems. No doubt there are stands that have little value and should be written off without budworm treatment. In other cases treatment after partial top kill has occurred may be of little value because of the poor stand condition.

   Recommendations
   Further research work is needed on stand dynamics and the analysis of individual trees to determine overall effects of the budworm and other organisms in both the short and long term.

7. The budworm has been studied by many scientists for over 50 years, but there are still many unknowns. We need to continue evaluations of the budworm problem to understand what some of the numbers mean. Presently, we do not know what a large egg-mass occurrence found this year will mean in a long-term sense. We also have problems with insecticide dosage. While we talk foliage protection, we still seem to prepare dosages based on percentage kill, which seems to be inconsistent with the objectives.

   Recommendations
   Control projects should be reviewed to determine whether they do, in fact, meet control objectives. Research should be directed to produce valid data on population numbers and to relate these to foliage protection. Dosages should be reduced where possible to correctly reflect the objectives.

8. Many papers referred to funding and revealed an apparent reluctance to become involved. Some evidently consider the eastern spruce budworm to be only a Canadian problem despite the large acreage of infestation in Maine; this comment relates mainly to the research effort and not to control.

   Recommendations
   The U.S. Forest Service should become active in spruce budworm research in both the eastern and western parts of the country. It is further recommended that a compact arrangement be developed between Maine and its adjoining Provinces to assure co-operative efforts in the long term. Further, an international commission should be established to co-ordinate all efforts on the budworm throughout North America. On some research projects

there should be joint teams of scientists working from the same research laboratories. There must be more attention given to co-ordinating control efforts so that all agencies and regions will be able to obtain needed materials. The long advance notice necessary to obtain chemical supplies will be difficult to meet but careful planning should help.

9. All of the papers presented were very clearly interrelated in considering the budworm, the forest, the market, and the needs of people. Specific areas were mentioned frequently, but in all cases the cry came through that more research is needed on the forest, the budworm, and the methods of managing both. Repeatedly we heard that in the future we must learn to live with the budworm, and we must develop a new philosophy of resource management to cope with this problem.

Recommendations

A joint Canadian-American research effort should be mounted to examine the dynamics of the spruce-fir forest and the budworm as they relate to the total problem. The joint effort would be designed to look at the short-term needs to control the budworm through data refinement, new technology, and further direct control development. More important would be the long-term study of the problem through intensive work by silviculturists, economists, managers, entomologists, pathologists, physiologists, and others to develop ways to meet the budworm challenge. Perhaps now is the time to recognize that the culture and management of spruce-fir forests is a budworm management problem and that our operations must be designed with that in mind instead of the classic culture related only to growth and production.

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state foresters' point of *view*

FRED E. HOLT
Director, Maine Forest Service, Augusta, Maine

State Foresters' offices are generally charged with preservation and development of the forest resources of their States, whether it be on State or private lands. They are expected to represent the public interest, however broad that spectrum, and provide leadership in good stewardship of the forest lands. The State forest agency serves as the working arm of the U. S. Forest Service in its relationship to State and Private Forestry matters. The Forest Service in turn shares the cost of funding programs which the States carry out on the State and private lands. The major programs are Cooperative Forest Management, Forest Fire Management, and Pest Control.

In 1921, following a severe spruce budworm outbreak from 1910-19, Maine recognized the need for professional expertise and hired Dr. Henry Pierson, the first State entomologist. Maine now employs nine entomologists and two pathologists, and maintains a laboratory in Augusta where the principal activity is the study of economically important insects and their control. Basic research is not our primary responsibility, although we aid and assist the U. S. Forest Service in operational testing under forest conditions. We do, however, fund the University of Maine to do spruce budworm research.

For the last several years, all personnel assigned to the Division of Entomology in the Maine Forest Service have given priority to the spruce budworm. We believe the staff has a comprehensive understanding of this insect pest and is in a position to make decisions which are in Maine's public interest.

With a tenfold increase in severely defoliated areas in a year and with statutory authority to take action, it did not require a great decision-making process for the Maine Forest Service to determine that control action should be recommended in 1975. However, the process of putting together a control project without assurance of funding, with too few aircraft to provide competitive bidding, and with only one registered pesticide available to do 180,000 acres out of a total of 3-1/2 million acres, could be considered a disaster in itself.

Funding

The U. S. Forest Service recommended deficiency apportionment of their funds to provide early assurance to the State that Federal funds would be committed. Hopefully, this recommendation will clear all the governmental hurdles so that when the Maine Legislature convenes in January, Federal funds will be known to be available.

We are, of course, concerned with earliest possible passage of the State appropriation request which will probably be $6,562,500. Funds will have to be available well ahead of the operation (set for June 1) and before the legislature adjourns. For the funds to be received in time, the legislative document has to be entered as emergency legislation requiring a two-thirds vote for passage. Because of the large amount of the request, we will need a great effort to get passage. We can ill afford to raise any opposition by suggesting use of any unregistered pesticide.

Early passage of the bill will be helpful in obtaining more competitive bidding on contracts. Overall savings are badly needed, since our best estimate of direct costs is now $3.75 per acre.

Aircraft

Specialized aircraft of the type required are not generally plentiful at the time of year they are needed. About 50 twin-engined aircraft are needed for insecticide application. The main reasons for using this type aircraft are to provide flexibility of operation and to meet weight limitations on the taxi strips where loading must be done. Two airfields will be needed to avoid traffic problems; additional outlying airfields may be used for fueling light observation aircraft. Early funding is desired to assure contractor performance.

Insecticides

At the outset, it is important to know the type and quantities of insecticide(s) to be used, for this will dictate the type and number of aircraft and the application rate(s) during the 3-week larval vunerability period. We must also know the cost of the insecticide(s) to facilitate early planning. Considering the present situation, we have to estimate maximum gallonage of those insecticides most readily available and plan on the highest cost quotes of insecticide manufacturers.

I will present only a few of the myriad problems of finding an available insecticide. The major problems are the lack of raw materials and solvents; whether there is an adequate supply of a registered pesticide; and whether an unregistered insecticide can be registered in time to allow accumulation of ingredients and formulation. How can we make a commitment in December 1974 so raw materials can be allocated for insecticide to be used in 1976? If we can get enough insecticide for only a third of the recommended acreage, is it justified to proceed with any control program?

We are all interested in maintaining a healthy environment for this and all other generations to come. But I also want to point out the care with which we need to proceed in the future to avoid such inflexible binds as we now have relative to available insecticide. The alternative of no control in 1975 could easily lead to a major disaster the following year due to wildfire. Continuing budworm expansion could easily engulf the entire 8 million acres of spruce-fir type forest in Maine. One year's mortality can kill the equivalent of the total annual harvest of pulpwood in the State. Because of the large area involved, inaccessibility, and limited harvesting capabilities, a large portion of the dead material could not be salvaged. Alteration of the closed crown canopy by harvest operations in deer yards and bordering streams and lakes has been an area of deep concern to game and fish biologists. Alteration of the crown canopy by uncontrolled spruce budworm infestation will be infinitely more devastating, based on the 1974 population trend.

We will be actively seeking the support of those with similar concerns and hope that this support will avoid the disaster which is sure to come unless a control program is mounted in 1975.

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wood supply: forest industry point of view

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Introduction

Great Northern Paper Company of Maine is a large manufacturer of newsprint and specialty papers, produced from roundwood and sulfite pulp. Our total annual consumption of spruce and fir pulpwood is approximately 900,000 cords.

The problems and production costs arising from the budworm infestation are multiple and complex. Today, however, I would like to consider just one of the major concerns of my own company and of the industry; that is, the problem of maintaining a *steady supply* of wood from the forest resource.

The present epidemic of the spruce budworm poses a major disruption of the wood supply. Briefly, I hope to explore with you the effect of that disruption on one forest industry in Maine and on one forest tract: first, a brief review of what actually happened to us during the infestation of 1910-20; and second, a projection of the probable effects of budworm losses on inventory levels, harvest volumes, and growth rates.

Perspective

Great Northern Paper Company began operations in the State of Maine in 1899 with the purchase of 338,000 acres of timberland and the construction of a pulp and paper mill at Millinocket. Production of this mill was 80,000 tons annually. The U.S. Bureau of Forestry helped prepare the original forest management plan which was based on a 50-year cutting cycle and an allowable cut of .10 cord per acre per year. The timberlands at that time supported a total volume of 2,596,617 cords of spruce and fir, or 7.68 cords per acre.

This original forest management plan was followed closely for the first 15 years, with an average annual cut of .12 cord per acre. Then in 1915 Great Northern foresters became concerned with the spruce budworm attack and the increasing mortality in spruce-fir stands. Cutting and timber salvage rates were rapidly increased, reaching their height in 1920, when 237,000 cords were harvested. By this time Great Northern owned over 810,000 acres of timberland and the rate of cut in 1920 therefore increased to .29 cord per acre.

After 1920, cutting rates were rapidly reduced as merchantable and salvageable timber became unavailable. The low point in the harvest period was in 1924, when only 31,000 cords were cut on company lands. The annual cut for the next *10 years* was only 44,000 cords on 1,500,000 acres of timberland, or an annual rate of only .03 cord per acre. Wood procurement to the mills during this period averaged over 300,000 cords annually.

Growth rates slowly improved through the 1930's and 1940's, and by 1950 new softwood growth was being measured and recognized. Mill expansions were planned and completed. Today the growth rate in spruce-fir stands has increased to over .25 cord per acre per year.

Casualty losses allowed by the U.S. Internal Revenue Service for budworm mortality amounted to 47 percent of the standing inventory as of the year 1919; 70 percent of the total stand of fir and 20 percent of the total stand of spruce were lost.

The structure and long-term impact of this last major budworm attack should certainly make us aware of future probabilities.

Projection

The projection, illustrated in Figure 1, is based on the premise that control of the budworm is minimal or will not be available for the long timespan. It also assumes that an effort will be made to salvage mortality and encourage growth through a significantly reduced cutting cycle, from the present 35-year to a 20-year cycle.

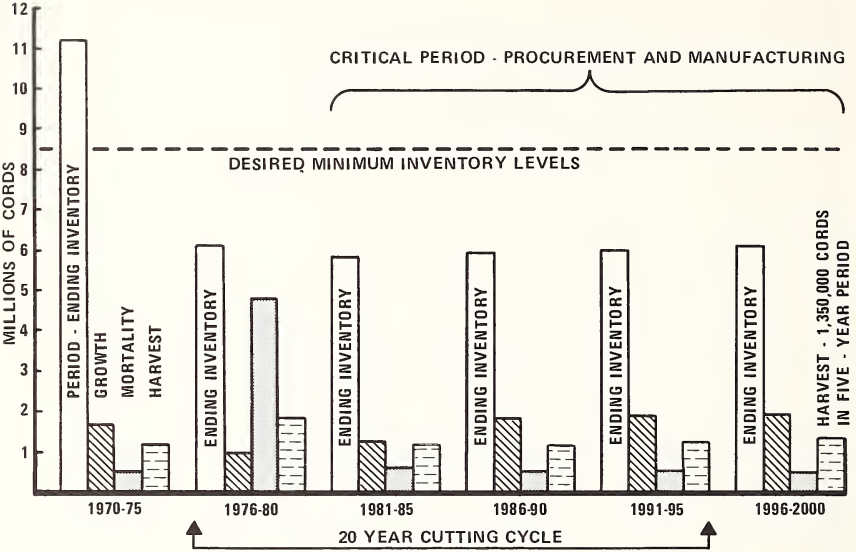

FIGURE 1.

Spruce budworm mortality effect on inventory levels of spruce and fir.

This could be considered a median-level projection and is summarized by 5-year cutting periods. The column indicating harvest includes mortality on the 45,000 acres cut over each year. Low point in harvest volumes is reached in 1985, when only 180,000 cords can be cut.

Assuming the same general rate of inventory losses (70 percent for fir, 20 percent for spruce) as in the last epidemic, we may make some long-term estimates of what could happen to a tract of Great Northern's timberlands (878,000 acres) that is within the heavily infested region of spruce budworm attack.

Figure 1 is a summary of these projections for inventory levels, growth, mortality, and harvest rates. As in the 1915 epidemic, spruce and fir mortality is assumed to be exceptionally heavy for a minimum period of 5 years, through 1980. Over 4,700,000 cords of spruce and fir are projected as the total mortality for this period, with a total salvaged volume through an 8-year period of 833,250 cords.

Such a projection quickly reveals the complexity of the budworm problem and shows that the elements of growing stock, mortality, harvest, growth, and cutting cycle are so interdependent that, as we manipulate one, we change all. The independent and uncontrolled element assumed in this projection lies in the estimated mortality of the stands and in the budworm itself. We may partially control inventory through cutting rates and improve growth by silvicultural treatments. Although we are assuming no control over mortality, we may control salvage rates to reduce losses. We may also reduce or lengthen cutting cycles either to reduce mortality losses on the one hand, or to improve logging costs on the other.

Let's examine the principal impacts from this survey and projection:

Time

The most important lesson from the 1915-20 epidemic and from our present projection indicates that time frames are long. Total elapsed time may be over 25 years from the initial loss of growing stock (forest capital), to recovery of a portion of that growing stock, and to again achieving acceptable growth rates.

Growth

A more rapid recovery of forest growth and restoration of growing stock have been considered and included in this projection of a 20-year cutting cycle on spruce-fir types. We note that by 1990 growth rates are expected to exceed present growth (1970-75). But even this may be too slow to build up the necessary growing stock. Most of this growth is expected to occur in stands and on trees which are considered unmerchantable under present utilization standards. It is not until the year 2000 that growth recovery begins to have a marked effect on the allowable cut.

There are, however, steps or options which an industrial forest owner might consider to increase growth and wood supplies during the critical procurement period:

Other Species

Encourage the use and growth of other species through the preliminary (mortality) period of 8 to 10 years and during the critical procurement period. Such species as aspen and hemlock are now being used in our own sulfite pulping, and Kraft pulping provides additional flexibility in the use of hardwoods, pine, larch, etc.

Artificial Regeneration

Develop planting programs using species of spruce which have shown some resistance to budworm attack. Although growth in plantation stocking will not reach maturity (even for thinnings) for 20 years, it will immediately effect a possible increase in allowable cuts.

Pulping Reasearch

Accelerate pulp research efforts in the use of small stems, juvenile wood, and the whole tree. Efficient utilization of cleanings and thinnings during the critical period will make a significant contribution to overall growth and the allowable cut.

Cutting Cycles

For the initial 10- to 15-year period, plan and schedule a further reduction in the cutting cycle to 15 or 10 years. Lower total volumes will be harvested per acre, but salvage volumes will be increased. A larger volume of residual growing stock will also be available for increased growth. Logging costs may be increased, but so will the future wood supply.

This projection is only a preliminary concept in evolving a forest management system for the budworm; many simulations in more detail are needed, and there are many cost alternatives and combinations which must be examined. Each region, State, forest type, and industry will have its own imperatives.

Summary

The mortality and immediate loss of growing stock from spruce budworm infestations are dramatic, obvious, and costly. However, the resultant effect of reduced growth rates over the long run will be even more significant and more expensive to forest industry.

The projection and example reviewed here on an 878,000-acre forest tract are considered median estimates, with an expected mortality *loss* of 4,700,000 cords and an estimated 50,000 cord shortfall possible in the allowable cut over a 10- to 12-year period. Expanded to proportional State levels in spruce-fir types (8,000,000 acres), expected mortality may well exceed 45,000,000 cords and the reduction of the allowable cut over a 10- to 12-year period may approach 450,000 cords annually (or 20 percent of present cutting rates).

Low growth rates will reduce allowable cuts, increase stumpage and logging costs, and may cause significant production losses in forest product manufacturing itself.

Federal, State, and industrial forest management, therefore, have a challenge and a commitment to undertake the long-range development of budworm research and control, forest management systems, and silvicultural practices which will reduce losses from budworm mortality and which will improve the future growth of the forest.

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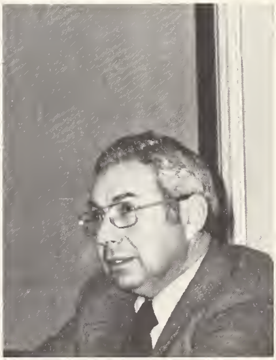
bugs money

For the past 2 days you have been discussing insect control problems, methods and techniques for control, and the effects of insects and diseases on overall forest management. There is a threat that the budworm may again go on a binge. However, it is not enough to ascertain whether an insect population will become epidemic. It is important to show there will be some impact on timber supply, recreation, and other uses; it is also necessary to determine which control techniques are effective in reducing the insect population. Even if we knew all of these factors, we cannot assume a policy to control all epidemics, especially in this age of tight money, inflation, and environmental concern.



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The policy objective people in positions such as mine would suggest is along the lines that we should invest in control programs to that point where the economic, environmental, and social benefits of control exceed the cost of control. Control requires capital. Capital is a fluid productive power. It is scarce and must be used wisely for many competing demands. When we choose to undertake a control project we must give up other goods and services that could be produced. Therefore, comparing benefits and costs is an essential part of decisions on whether or not to implement a control program and on decisions concerning technique, how much, and when.

We must also recognize that there are multiple objectives. We must analyze the impacts on local employment and income, the environmental impacts, and the impacts on particular groups of people. Benefits and costs are not evenly distributed in any government decision. Some groups benefit more than others, and some pay more than others. Thus the "goodies" are redistributed. And these "redistribution-of-wealth" effects are at the heart of the political controversies that surround most government decisions, including major insect and disease control programs. Therefore, multiobjective analyses of these effects are vital to decision makers.

My purpose is not to offer a lesson in benefit-cost analysis, input-output analysis, simulation, or any of the other analytical techniques; rather, I would like to make a few observations about some of the problems we have had in such analyses.

A fundamental principle is that we must compare the proposed control program to the "without" situation. The decision to control should be based only on the difference in benefits and costs between the "with" versus the "without" situation. It is not the total values involved, but rather the marginal changes that are at issue. This is sometimes a troublesome concept to convey.

We must also recognize that calculating the benefits of insect control programs can be very complex. The typical problem involves a considerable amount of uncertainty, with the need to approach the problem in a probabilistic manner.

Entomologists must first predict what will happen to the insect population "with" versus "without" controls. It appears that we often have good models of the insects, their buildup etiology, sex lives, tastes, and lifestyles.

However, we must also predict the effects of these insect populations upon vegetation. Here we often lack models adequate to determine not only the immediate effects on vegetation but also the long-term effect of the epidemic on the forest ecosystem. What we are really concerned about is the effect on eventual yields. In young, mixed-species stands, for instance, there might be considerable resiliency.

There are also problems of determining secondary effects, such as changes in fire occurrence and risk. All of these assessments involve probability estimates, which in combination make the estimating job fairly complex and uncertain at best.

To further complicate the issue we must value those probable losses in socioeconomic terms. Since most of the timber will not likely be harvested immediately, we must predict a value of those losses at the time of harvest or place a value on the delay in harvest date. Additional uncertainties in predicting prices arise. Of course, if actual losses in value will occur a long time in the future, the discounted values are often quite small. This is often the case in young stands.

Since we have a very complex probability problem one might suggest such techniques as Monte Carlo simulation or Markov-chain models. However, there is seldom enough time, enough available skills, or enough data to use sophisticated models. Timeliness of decisions is of the essence; so we are faced with doing the best we can with the skills, data, and time we have available.

However, a lot can be done on the back of an envelope. Probably the best mechanism I can suggest to help all of us straighten out these problems is to simply compute the predicted time stream of effects, outputs, benefits, and costs without the project and for each alternative control possibility. Then effectiveness-cost, benefit-cost, and other relatively simple analyses can be performed. It may be necessary to reanalyze the data several times before decision makers act. This reanalysis capability is important in testing critical assumptions and in updating new information. But the basic information on the expected physical and biological effects of each alternative is crucial to any analysis.

In a sense, insect control is a game of strategy. There is considerable risk and uncertainty. What strategy criteria do we use to handle risk? I would suggest that you spend some time looking at game theory approaches. Should we use a "minimax" rule where we minimize the chance of the worst possible (5- to 10-percent chance) outcome? Or should we base our decision on the average expected (50-percent chance) outcome? The costs will vary considerably depending on which of these strategies predominates. The possible benefits or value losses may also vary considerably. Therefore, the choice of criteria may vary considerably with the situation. For instance, a recent article in the Washington Office Daily News Digest stated the discovery of a 20-acre patch of down spruce in the Coconino National Forest. Apparently this poses a threat of a possible buildup to epidemic proportions—at least that was the implication of the brief news article I saw. In that situation both the cost and the benefits of control would seem to be rather small. The calculation could be based on that small patch and one might reach the conclusion that the cost of control was not justified, basing the decision on an average expected outcome. But what if the situation did blow up into a major insect outbreak? The decision not to control in that case would be false economy and obviously a minimax rule should be used. On the other hand, when an epidemic reaches the tussock moth control situation then overcontrol to achieve a minimax objective might be extremely wasteful and unnecessary. Control for the average expected outcome would be more desirable.

There are other economic problems if we take a broader look at insect control in the forest management situation. I recently led a group of foresters on a silvicultural tour of Germany. The Germans are faced with an interesting question of whether or not to shift from intensive forest management toward more extensive forestry, with a particular regard for insect and disease risk questions. Artificial regeneration is common. Experience has shown that management must be intensive to protect the initial and subsequent investments. With rising costs of labor and restrictions on pesticide use, the question arises: "Should the present level of management intensity be continued?" The gnawing concern is that if intensity were relaxed, a good part of the investment would be lost through insects and diseases.

My best advice in facing the analytical challenge is to include competent, experienced economists or program analysts in your project and program formulation teams. The business is not so simple that a cookbook can be written which any forester can use to devise a sound multiobjective analysis. There must be a true interdisciplinary approach to problem solving, and the social sciences must be included. I also suggest that economists be involved from the beginning when comparing alternative controls. There are often several intermediate decisions that determine whether or not a final proposal is economically sound.

We have a draft Forest Service Manual directive—Framework for Analysis of Alternatives. It is very general and will not provide you with a specific technique for the spruce budworm problem, but it does lay out some of the fundamental analytical policies we would like to see used on all programs. There is still a challenge to develop specific analytical techniques that will fit the particular problem at hand. I know you have been working on this.

We would also like to offer our assistance. We have tried to respond to requests for analytical assistance on major insect problems, and I think our people have usually been quite helpful. We are currently building up our staff in line with the new reorganization which placed major emphasis on improving our program and policy analysis. Within a few months I hope that our analytical capability will be considerably improved so that our shop can be more responsive to requests for assistance and consultation.

You have some major questions before you. I hope that we rise to the challenge to integrate our entomological, forestry, ecological, and economic analyses to provide sound bases for the decisions. Armed with such analyses the case for obtaining needed funds becomes much stronger.

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environmental protection and enhancement benefit to cost ratio

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When there are pest outbreaks, whether it be the spruce budworm or any other damaging pest, we must think very seriously of the most efficient means of protecting our resources. In the forest environment we think of protecting timber, recreation, watersheds, fish and wildlife habitats, and reducing the amount of fuel available for wildfires.

The benefits of using pesticides for protection are obvious. However, there has been increasing public awareness and concern regarding all activities which may pose adverse effects upon the environment, including those undertaken by Federal and State agencies and the private management sector. Some pest management activities have become controversial because of the frequent use of chemical toxicants. As a result, the public is interested in knowing what is being proposed or done.

The desire by the public to become involved in the decision-making process provided the impetus for Congress to enact the National Environmental Policy Act of 1969 (NEPA). Most of you are aware of the act because of the Environmental Impact Statements that it has prompted. The requirement of these statements is only a part of the act.

Let me take a few moments to review the substance of NEPA. Basically, this very important piece of legislation has four purposes. The first is to declare a national policy which will encourage productive and enjoyable harmony between man and his environment. The second is to promote efforts which will prevent or eliminate damage to the environment or biosphere and stimulate the health and welfare of man. Third is to enrich the understanding of the ecological systems and natural resources important to the Nation. Finally, to establish a Council on Environmental Quality.

The first two purposes are as American as motherhood and apple pie; there are few people who will disagree with their intent. Simply stated, it is the responsibility of the Federal Government to improve and co-ordinate Federal activities so the Nation may, for all generations, assume a healthful, productive, and pleasing environment without degradation or other undesirable or unintended consequences.

The formation of the Council on Environmental Quality was to provide the President with a staff to prepare a report to Congress on the status of the environment; current and foreseeable trends in the quality, management, and utilization of the environment; and the effects of these trends on the social, economic, and other requirements of the Nation. Also, the Council reviews programs of the Federal Government and makes recommendations for legislation dealing with the environment.

That section of NEPA germane to us is the one concerned with planning the decision-making process and Environmental Impact Statements. Federal agencies are directed to use a planning and decision-making process that employs an interdisciplinary approach and ensures the integrated use of the natural and social sciences and the Environmental Design Acts. Federal agencies are also directed to identify and develop methods and procedures that will ensure that presently unquantified environmental amenities and values are given appropriate consideration in decision making, along with economic and technical considerations. Finally, Environmental Impact Statements are to be prepared for all activities significantly affecting the human environment. Through judicial interpretation, the provision for an Environmental Impact Statement has been made applicable to many actions that, until recently, were left solely to the discretion of the Federal agencies without any public input or comment.

Many of these statements have been based largely on guesswork and this has caused severe criticisms. However, to reduce these uncertainties and to more fully elucidate the no-action alternative, the Forest Service, other Federal agencies, and the private sector will have to expand their environmental research efforts considerably.

For a realistic benefit-risk ratio, and I am now speaking generally of insect pests, more adequate answers must be provided for questions such as:

> What is the relationship between egg-mass densities and resultant populations of defoliating larvae?
>
> What is the relationship between stand conditions and the damage done to the trees by given populations of larvae?

Answers to these questions could be considered predictions based upon "infestation dynamics."

> What is the exact social and economic impact of a decision not to control the infestation?

This area could use greater input by sociologists and economists.

> What is the overall plan for silvicultural treatment or harvest for the areas being considered for treatment?
>
> What contingency plans are there in case unpredictable weather prevents treatment at the optimum time?
>
> How are the adverse effects of a defoliation in relation to wildlife habitat and watersheds different from those of harvesting?

This question refers to an instance where fish and wildlife habitat protection is considered a benefit.

These are examples of several areas where additional information can improve upon our decision making. The lack of knowledge and technology for assessing the full impacts of pests on resource productivity and values represents perhaps the weakest point in present forest pest management strategies.

Another concern to recognize in environmental protection and enhancement activities is that of endangered species. Many are aware of the Endangered Species Act of 1973 that reaffirmed and strengthened the Nation's commitment to conserve threatened and endangered species. Public Law 93-205 requires Federal agencies to utilize their authorities to further the purposes of this act, by carrying out programs directly and through their co-operators for the conservation of threatened and endangered species. In addition, it requires them to ensure that actions authorized, funded, or carried out do not jeopardize these species or their habitats.

The Forest Service and all other Federal land management agencies have a definite responsibility and opportunity to take affirmative steps to enhance the habitats of endangered species.

I have highlighted NEPA and the Endangered Species Act because they may have broad and far-reaching effects upon our way of doing business. These two acts are significant in any program that we undertake.

Another act of Congress which also promises to ensure environmental protection and perhaps enhancement is the Federal Insecticide, Fungicide, and Rodenticide Act, as amended, known as FIFRA. This act regulates both the registration and the use of pesticides.

Since some forest pest management activities use pesticides, this particular piece of legislation can have both detrimental and beneficial effects upon the way we do business. A full explanation of FIFRA, as amended, is beyond the scope of this session, but many are aware of this act and no doubt will soon become very familiar with it.

The Forest Service, which is responsible for forest insect and disease surveys and suppression projects on Federal lands, is guided by the Secretary's Memorandum No. 1799, USDA Policy on Pest Control, which states:

> It is the policy of the Department of Agriculture to practice and encourage the use of those means of practicable, effective pest control which result in maximal protection against pests, and the least potential hazard to man, his animals, wildlife, and the other components of the natural environment.
>
> Where chemicals are required for pest control, patterns of use, methods of application and formulations which will most effectively limit the impact of the chemicals to the target organisms shall be used and recommended. In the use of chemicals, the Department has a continuing concern for human health and well-being and for the protection of fish and wildlife, soil, air, and water from pesticide contamination.
>
> In keeping with this concern, persistent pesticides will not be used in Department pest control programs when an equally safe and effective nonresidual method of control is judged to be feasible. When persistent pesticides are essential to combat pests, they will be used in minimal effective amounts, and applied only to the infested area at minimal effective frequencies.

As a result of public interest, some of it reiterated by Congress, and recognizing our lack of knowledge or our failure to use existing knowledge, our Forest Insect and Disease Management staff and field counterparts are taking steps to ensure that environmental protection and enhancement are synonymous with forest pest management. We are increasing our activities in the development and application of insect and disease population surveys and evaluation of impacts of pest populations.

We are also accelerating our efforts to take experimental chemicals and control techniques to the field in pilot control studies. We hope this will enable us to develop a number of alternative control techniques, rather than relying primarily upon one or two methods.

We are all aware of the benefits of forest pest management projects. I have outlined some areas of potential risks that have been recognized by the people of the United States. This recognition spawned the environmental protection legislation. We now have the opportunity and obligation to more fully elucidate both the benefits and risks of forest pest management in the United States, and we must continue to do so.

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the ecological consequences of chemical control of spruce budworm

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presented by J. J. FETTES

Spruce budworm epidemics are certainly ecological disasters! The decadence of large tracts of spruce-fir biome is not only a severe economic loss in most instances, but also of drastic ecological impact, comparable to a major fire, drought, or flood. The inevitable sequel to a forest killed by budworm is a major fire. This is not to say that fires per se are ecologically unacceptable, but when millions of acres face this hazard simultaneously the result can well be an ecological desert for many decades. Valuable habitat for many species, some endangered, is lost when extensive areas of the environment are destroyed by fire. Thus, the first ecological alternative to a chemical pesticide to consider is that of no control.

In terms of environmental impact, the budworm control operations in eastern Canada present the longest continuum of data in existence. In evaluating the evidence on ecological side effects, I am calling heavily upon data, both published and unpublished, collected by scientists of the Chemical Control Research Institute.

Chemicals have been applied to the forests of eastern Canada to control spruce budworm for the past two decades. For the first 15 years, DDT was the sole insecticide used. Initially it was distributed at relatively high dosage levels over wide areas, with little regard for topographic features such as rivers and streams; later, the water resources were avoided and concentrations were reduced. In aquatic habitats, insecticide concentrations were initially relatively high even where avoidance patterns were used; however, residues quickly subsided and after a short while persisted only in sediment in minute quantities. The record in terrestrial habitats is somewhat confounded by multiple users; whereas the bulk of insecticide was distributed to protect forests against spruce budworm, significant quantities were also applied by woods operators to control biting flies. Notwithstanding these complications, it is now abundantly clear that much of New Brunswick's soils are carrying substantial loads of DDT and its metabolites. It is of interest to note that the metabolite DDE is present only in trace amounts, and this has certain ecological implications that will be discussed later.

The first observable effect following treatment by DDT is a large-scale cessation of activity by flying insects. Dead insects, both target and nontarget, are soon readily visible on open ground. Where dosages are extremely high it may be possible to locate some birds suffering from insecticide tremors, and many of these will eventually die. Rarely does one find mammals in this condition, because they are generally secretive and tend to avoid direct contact with insecticide clouds. In aquatic environments insect fauna are affected first, and severe mortality usually occurs. Fish, especially the very young ones, frequently experience moderate to severe mortality.

Long-term effects on natural systems are difficult to measure and the results of such studies are open to differing interpretations. Since the withdrawal of DDT, insect fauna of both aquatic and terrestrial ecosystems in treated areas has apparently returned to normal. It therefore appears that in spite of drastic initial mortality, no permanent or long-lasting change has taken place. Long-term records on fish, especially salmon, also indicate that no serious population consequences could be attributed to DDT, even when considering years when drastic reductions of fingerlings and fry were recorded. Survivors evidently experienced less intervening mortality, thus compensating for the early reduction in numbers. Indeed, there are several well-documented cases of salmon fry experiencing severe mortality, while their age-class survivors produce record return runs. The dynamics of these populations clearly compensated for the initial reduction, and in terms of bioproductivity the initial impact on the population was an illusion. Similar results have been indicated for the current insecticide fenitrothion.

The effects of DDT treatment on birds and mammals have been examined in New Brunswick over the past two decades by a number of scientists. The initial impact on these forest components has never been great, although after many operational applications there have been limited reports of dead or injured animals, likely the result of accidental repeated swathing or drift concentration. Intensive studies by this author on the long-term effects of DDT on the populations and ecology of birds and mammals indicate that there are no detectable changes in population numbers, breeding and rearing success, and food habits attributable to the insecticide or its derivatives. Populations of all components measured before DDT application to New Brunswick forests are comparable in every respect to those after two decades of constant exposure to the insecticide.

There are some measurements of the concentrations of DDT and its metabolites in the tissues of New Brunswick mammals and birds. Two curious facts stand out in these studies: (1) although concentrations of the pesticides in the environment range from very low to very high, concentrations of the insecticide and its derivatives remain at relatively low levels in animal tissues; and (2) both in the environment and in living tissues, the highly toxic degradation product DDE appears in only trace amounts. In an intensive study of the brains of small mammals taken in areas heavily contaminated with DDT, the highest concentration was 0.175 p.p.m., well below the danger threshold. A special case, and one that has received considerable attention by sportsmen and the public at large, is the woodcock. Legislative tolerances of human consumption of DDT-contaminated foodstuffs give a maximum of 7 p.p.m. Fresh weight determinations on woodcock ranged to 4 p.p.m., but separate analyses of lipids yielded determinations up to 80 p.p.m. On the strength of the latter determinations, woodcock hunting was prohibited for several seasons, even though the lipid components are largely removed in the preparation process. In spite of carrying low to moderate loads of DDT, woodcock eggshell thicknesses were reduced by only about 2 percent. Thus, what on the surface appears to be an alarming situation, in reality has insignificant implications for woodcock population dynamics and human health hazards.

Since the withdrawal of DDT as a forest insecticide, the principal replacement chemical has been fenitrothion. This compound, applied at the recommended dosage, is only mildly toxic to the nontarget components of the system. Where overlapping or unusual concentrations of the insecticide occur, some mortality of birds and small mammals can be expected, but this is almost exclusively confined to the juvenile components of the population. Applied even at 10 times the recommended dosage, only minor disruption of vertebrates occurs. Damage in such circumstances is largely confined to the openly exposed species and individuals. Some species are more susceptible to disruption than others, but the total impact even at extremely heavy applications is surprisingly moderate. Long-term effects are difficult to assess because the chemical persists only fleetingly.

Damage by fenitrothion to biological systems in aquatic environments is considerably less than, but of the same nature as that of DDT. Accidental treatment of streams has injured aquatic insect populations and in rare instances young fish, but ecologically speaking this mortality is minimal and of no lasting importance. The chemical obviously can withstand the scrutiny of critical evaluation.

Fenitrothion has recently been criticized as being highly damaging to pollinating insects such as honey bees and wild Hymenoptera. Experiments in which hives of domestic bees were exposed to the chemical clearly indicate that these charges are not well founded. Hives treated with many times the recommended dosages survived easily, continued to produce, and maintained constant growth. Disruptions to adults and brood, even under severe treatment conditions, were never more than 5 percent, scarcely an alarming impact on either the honey production or pollination. Similar, but slightly greater impact on the wild Hymenoptera was achieved. This leads to the conclusion that when applied as recommended, fenitrothion does not seriously influence wild bees and wasps, or domestic honey bees.

In developing aerial spraying of insecticides to control forest insects, one of the earliest warnings of impact on nontarget organisms came from the aquatic environment. So dramatic was the change in aquatic biota following treatment by DDT, that an immediate tactic to avoid significant waterways was invoked. Of particular concern to ecologists was an apparent drastic kill of juvenile fishes and moderate mortality to the larger ones. Stream insect populations also declined to the point where ichthyologists registered concern lest food chains become altered to the detriment of commercial and game fishes. The successors to DDT have exhibited various degrees of disturbance to aquatic life, but this too has been immediate. Long-term residual effects in aquatic environments are of only minor concern because of the relatively low degree of solubility of most insecticides in water. Persistence, even of those of long life, is not a major factor, although there is some evidence of retention in sedimentary deposits. Emphasis, therefore, must be principally directed toward initial disturbance rather than long-term impact on the aquatic environment.

Except for voluminous research on the impact of insecticides on birds, data on the majority of components of terrestrial ecosystems are sparse. Permeation of chemicals into the abiotic strata and their cycling through the vast network of the biota form a complex study, which must be understood in principle before control tactics with due regard to ecological disturbance can be contemplated. And in this respect we should not be content with a mere cataloging of concentrations of residues in the various components of the system, but rather with a modeling of the ecological consequences of the phenomena that these concentrations represent. Erroneous conclusions and unfounded implications have frequently followed upon the results of chemical cataloging of pesticides in various environmental components.

The chlorinated hydrocarbons are among the most persistent of pesticides. Residues of DDT have remained in biological systems for many years, apparently unchanged. They have, furthermore, been recovered from virtually every component of the environment in which they persist, notwithstanding the earlier confusion that existed in differentiating between DDT and PCB. Few energy transfers can take place in such systems in the absence of DDT or its metabolites. Modeling the cycling of this contaminant in the terrestrial environment, however, requires more information than is currently available. For example, we know that the chemical half-life of DDT may be many years. What we do not know, however, is the biologically available portion of the compound throughout this span. The only concrete information available on this persistence in forested areas will be considered later, but suffice it to say that many current assumptions bear no relevance to reality.

Persistence of the successors to DDT and its relatives is greatly reduced. In terrestrial systems this is possibly the most significant factor to be considered in determining the use of a material, and most of the current insecticides pass persistency tests. Certain taxa, for example, Hymenoptera, are particularly vulnerable to some of the insecticides in current use and careful tactics in formulation and application may be necessary to provide adequate protection to highly susceptible groups. Because of the variable solubility of most pesticides and their general affinity to organic material, even the modern nonpersistent materials may for a time be "locked in" to the ecosystem. However, once the source becomes unavailable, either by discontinued use or by degradation processes, the total amounts of the material within the ecosystem dilute rapidly.

Birds are probably the biotic component subject to greatest public concern with respect to hazards from insecticides. Most birds are diurnal and are thus active at times when most insecticides are applied. In addition to direct contact with insecticide spray clouds, they are vulnerable to consumption of freshly contaminated foods, before the pesticide component has had an opportunity to commence to degradate. Some compounds, including the chlorinated hydrocarbons, are only mildly toxic to birds at concentrations suitable for forest insect control; others, such as phosphamidon, are highly toxic, even at the recommended levels. Immediate effects on birds are nonetheless relatively rare, and most research indicates little or no initial hazard to birds. Two important long-term side effects currently receiving considerable attention are the magnification and thin eggshell phenomena. The former is the passage of persistent chemicals through food chains so that they accumulate or "magnify" at the tertiary productivity levels. The latter is the gross effect of certain chlorinated hydrocarbons of causing eggshell thinning in certain avian groups, particularly the raptors. In spite of the volumes of literature on short- and long-term effects of toxicity, the ecological and population consequences are not clearly understood, and there is very little scientific basis in the popular belief that the immediate and long-term impact of forest insecticide treatments have serious population implications. Almost all evidence relating damage to avian populations with forest insecticide treatment programs is circumstantial, conjectural, and inconclusive.

Notwithstanding the incomplete nature of the evidence relating damage to avian populations with insecticide treatment, the importance even of implications of ecological impact makes it mandatory to provide protection stratagem. The trend towards using nonpersistent chemicals removes much of the danger of possible insidious long-term effects. Coupled with careful examination of the immediate impact, this provides a valuable screening process in the selection of suitable insecticides. Techniques in application, expecially in timing of treatment, are also useful in reducing possible damage to birds. Recent trends toward night spraying tend to further reduce hazards due to contact exposure, except for nocturnal raptors.

The public is less concerned over the effects of synthetic chemicals on forest mammals than birds. Consequently, much less research emphasis is appended to the implications. In most instances toxicity trials have been confined to oral contact and subcutaneous treatments to a small spectrum of laboratory mammals. Results from these types of experiments, which perhaps serve to delineate broadly the maximum acceptable limits of treatment, bear little relevance to actual ecological immediate impact, and there is some evidence of the accumulation of these compounds at the terminals of mammalian food chains. Of some concern are the wild ungulates due to their use as game, but there are few instances where artificial compounds in their tissues exceed those found in domestic stock. The mammalian toxicity of most insecticides closely parallels their avian toxicity.

Because most forest mammals are nocturnal in habits, the implications are reciprocal to those of birds. In devising techniques to reduce hazards to birds, we should be alert to the implied relationships to mammals. In general, however, protective behavioral measures by mammals will tend to reduce immediate impact.

A good deal of the scrutiny of the environmental effects of pesticides in forest environments has been directed towards the compound fenitrothion. There are, however, several other alternative insecticides in widespread usage that have been examined critically by our staff. Of about the same magnitude of hazard as fenitrothion, are Matacil and Zectran. Phosphamidon is considerably more toxic to birds, but demonstrations indicate that this too can be used with minimal hazard provided adequate technology is employed.

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impact of forest diseases in suppression decisions

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Insects and diseases play an integral role in any forest ecosystem; however, little work has been done on the interrelationship of these organisms, especially in relation to populations of a defoliating insect (McKnight, 1968). Effects of various diseases on the tree or stand can occur during two somewhat distinct time periods: (1) during the course of the insect buildup, and (2) following the outbreak with numerous weakened or dead trees present.

The types of diseases affecting hosts of eastern and western spruce budworm are extremely diverse. They include needle casts, stem cankers of various kinds, dwarf mistletoes, and the stem and heart rots. The effect of these diseases ranges from a loss of vigor to loss of merchantable wood or even to mortality of the host tree. Some of the disease organisms are extremely virulent and act rapidly, whereas the damage caused by others progresses slowly over a relatively long period of time.

In the forest ecosystem which includes spruce budworm, an interaction of many entities, both living and nonliving, can influence all facets of the ecosystem, including the impact of those diseases present. Moisture, temperature, soil types, other insects, tree density, competitive plants, and many other factors all interact. The influence of this total interaction within the ecosystem and the direct result on any one part of that system (i.e., the tree, the spruce budworm, or the disease organisms) are not well understood. However, certain individual components, such as temperature and moisture, are critical in the development of a disease outbreak.

I would like to highlight certain disease conditions that may influence suppression decisions for the spruce budworm. For the most part, this relationship has not been considered by past speakers at this Symposium nor has it been discussed in previous Environmental Impact Statements developed for spruce budworm suppression projects in Maine or Minnesota (USDA Forest Service, 1973 and 1974).

In examining the problem, I do not plan to get into a controversy on the relative importance of insects versus diseases. I hope to point out voids that exist in our understanding of a tree disease–spruce budworm complex. What additional information could be utilized by the land manager in making the best suppression decision possible? What additional research is needed to provide this information? However, there are disease considerations which could be readily evaluated using our present knowledge. They are often overlooked even though they could materially affect suppression projects.

The prime factors in making a suppression decision must be the insect population, its trend, the effect on the host, and the practicality of a suppression method. However, perhaps equally important is the condition of the stand being considered for treatment. What diseases are present that could have sufficient impact to offset the benefits of the suppression effort?

Over the past several years, numerous studies have been conducted by pathologists to determine the amount of decay in various age stands of spruce, balsam fir, Douglas-fir, and the true firs (McCallum, 1928; Basham et al., 1953; Thomas and Thomas, 1954; Davidson, 1957; and Hinds et al., 1960). Although these studies were conducted in various parts of the United States and Canada, differences in the incidence of decay based on localities within each study area are evident. Davidson (1957), for example, examined balsam fir at seven localities in the Atlantic Provinces. The percentage of trees with decay in the 61- to 80-year age-class ranged from 24 to 54 percent. He suggests, that in addition to location, such factors as species of decay fungus, rate of tree growth, stand density, and such climatic factors as moisture, rainfall, and length of growing season can influence the amount of decay present in a stand.

Some studies indicate no difference in the amount of cull when comparing rapid versus slow growth in trees (Spaulding and Hansbrough, 1944), whereas other studies indicate slow-growing trees are more susceptible to decay.

In studies on subalpine fir, Hinds et al. (1960) found a marked difference in the amount of decay between plot areas throughout Colorado. This might suggest that under certain instances microclimatic conditions could be an important factor. Age of stand was shown by Davidson (1957) and Hinds et al. (1960) to have some influence on the increased incidence of decay, which substantiated earlier studies. However, since the correlation was not consistent in all age-classes, Hinds suggests that tree loss from wind breakage or windthrow could account for the decline in decay he found in some older stands.

In addition to the heart rots and decays, another disease often present in spruce budworm infested Douglas-fir stands of the West is dwarf mistletoe. The incidence and degree of infestation by this parasitic plant affects the yield from infested stands. By collecting additional data on the distribution and intensity of infection, the land manager would have a better total picture of stand conditions and thereby be able to make a more informed decision on suppression action.

These examples illustrate the diseases that could affect any stand being considered for an insect control project. In general, evaluation surveys to determine the incidence of diseases that affect the condition of stands have not been made. This information should be collected and closely evaluated to make more realistic decisions on suppression projects.

Research and evaluations done in the past indicate the need for additional work to determine more accurately the factors, such as site, locality, etc., that affect the amount of decay or other diseases present in forest stands. With less rot present prior to the insect outbreak, the host trees may better survive the effects of defoliation. The losses that occur in "healthy" stands may not be as severe as with trees affected by some disease.

In the postinfestation period of an outbreak, the loss caused by forest diseases is related to the deterioration of defoliated trees. In studies conducted in western Ontario, Hansbrough (1947) found that balsam fir deteriorated rapidly after being killed by spruce budworm. The first year generally had little effect on the increase of decay; during the second year, about 50 percent of the trees were severely decayed; and after 4 years 100 percent of the trees were classed as cull.

Since these early studies, several additional workers have investigated this problem in balsam fir. Basham and Belyea (1960), working in the same area as Hansbrough (1947) but with a larger sample base, had somewhat different results. They found rapid deterioration the first year after mortality, but even after 5 years, 48 percent of the volume was classified as sound and thereby considered recoverable. In studies conducted in the Green River watershed in New Brunswick, Stillwell and Kelly (1964) found that advanced decay progressed faster in trees from areas of light mortality as compared with trees from areas of heavy mortality. They attributed the lower losses in the heavily infested area to greater exposure to sunlight and better air movement. The trees died more rapidly, but the moisture content of the wood was lowered sufficiently to retard development of decay organisms. Recently Sterner (1970) studied two areas that had been infested by spruce budworm for a 7- and 9-year period. The incidence of butt rot generally present in the stand for the first 4 to 5 years remained relatively constant. After the fifth year, the incidence of butt rot increased markedly.

This work by Sterner (1970) suggests that in addition to an increase in decay after mortality, the incidence of rot intensifies in trees weakened by severe defoliation. This factor may not have been reflected in earlier studies by other workers. He also indicates trees subjected to little or no suppression from budworm defoliation had a higher incidence of decay than nonsuppressed trees in another stand subjected to the same conditions. Therefore, factors other than budworm defoliation, such as site or stand history, may play a role in this increased decay.

Deterioration of the western tree species attacked by spruce budworm has not been investigated, although some studies have been concerned with deterioration of trees attacked by hemlock looper or bark beetles. Utilization and marketing specialists in the western Regions have made the following observations: (1) Douglas-fir generally dries rapidly on the stump and can be used for several years following mortality; (2) old-growth stands of grand and alpine fir which normally have a high incidence of decay deteriorate quite rapidly following mortality; and (3) product use often dictates the time over which dead material can be utilized by "checking" the wood—a limiting factor in relation to use as dimension stock.

We therefore find that forest diseases can have an impact on suppression decisions if their incidence is sufficiently heavy to affect stand condition during or after the buildup of the spruce budworm. Considerable variation in the type and severity of disease is known to occur between stands. With most of the diseases, we often know the "what" of a situation (or what diseases are present), but the "why" is the difficult part (why do we have a variation in intensity, etc?). I have cited a few examples of disease situations which should be considered in making a suppression decision. Undoubtedly we will discover other relevant situations as our knowledge of the forest ecosystem increases.

As a final comment, I do not know of any studies where host condition has been studied as a contributing factor to a spruce budworm buildup. We should investigate the influence of the many factors in the forest ecosystem as they relate to both the budworm and the host. We may then be able to better answer more questions about the spruce budworm problem.

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influence of spruce budworm moth dispersal on suppression decisions

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The subject of adult moth dispersal has little meaning unless we relate it to entomological considerations in a suppression program. To put the dispersal process in perspective, I would like to detail the procedure that forest entomologists in the State of Maine use for making a spray recommendation. I will then discuss some of the questions raised when massive numbers of spruce budworm moths and subsequent increases in egg masses are encountered.

Entomological Procedure

The first step in the spruce budworm evaluation program is a series of low-level flights conducted annually at the peak of foliage discoloration. Observers fly over the entire spruce-fir area mapping the intensity of defoliation.

In August an extensive egg-mass survey is conducted. Balsam fir branches are collected in approximately 1,000 different locations and the numbers of egg masses on each are counted. Using a sequential sampling plan (Kettela, 1972), the collection point is classified for an infestation level on nil, low, medium, high, or extreme (Table 1). Each of these categories implies a certain amount of expected defoliation for the next year. For example, a location classed as "medium" has an expected defoliation of 31 to 65 percent of the new shoots, and an "extreme" infestation is expected to result in 90- to 100-percent defoliation of the new growth.

Table 1. Table of conversions from egg-mass density to infestation level

Egg masses per 100 square feet	Infestation level	Expected defoliation (percent)
0	Nil	0
1 - 99	Low	1 - 30
100 - 239	Medium	31 - 65
240 - 399	High	66 - 90
400+	Extreme	90 - 100

At each egg-mass collection point, the stand is rated on current defoliation, previous defoliation, and tree vigor. Current defoliation is classed into five categories ranging from trace (0 to 5 percent) to severe (greater than 81 percent) (Table 2). Previous defoliation contains six intensities ranging from trace to dead trees (Table 2).

The recovery or vigor of the trees is judged as good, fair, or poor, depending primarily upon the general stand production of buds and shoots (Table 2).

Table 2. Spruce budworm defoliation and damage recovery guides from the Maine Forestry Department, Entomology Division[1]

Rating	Stand Condition
For current defoliation on fir, use the following guide:	
Trace	0- to 5-percent defoliation
Light	6- to 20-percent defoliation
Moderate	21- to 50-percent defoliation
Heavy	51- to 80-percent defoliation plus some shoot axils missing

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[1] All of the above categories are for general tree condition in the sample area, rather than merely for individual sample trees.

Table 2, continued

Rating	Stand Condition
Severe	>81-percent defoliation plus most shoot axils missing
For previous defoliation on fir, use the following categories:	
Trace	Little or no apparent defoliation except to current year's foliage.
Light	Some defoliation evident on previous growth, particularly on previous year's growth; no bare tops.
Moderate	Thin crowns; short, bare tops; defoliation evident on at least 2 previous years' twigs.
Heavy to severe	Marked defoliation on 2 or more years' growth; crowns thin and grayish in appearance; 2 feet or more of bare tops.
Dead tops	Tops of trees in the sample area dead.
Dead trees	Dead trees present in the sample area at the time observations are made.
For recovery of foliage after spraying or for vigor of trees in unsprayed areas:	
Good	Current foliage apparently normal or nearly normal. Trees evidently capable of rapid recovery.
Fair	Shoot production moderately affected; obviously less vigorous but with evidence of ability to recover.
Poor	Current shoots present but sparse. Trees clearly demonstrating serious deterioration of growth capability and survival. Buds for production of next year's growth small and weak or lacking.

All information on tree condition and egg-mass numbers is combined into a hazard rating system, which assigns each sampling location a hazard rating number (Table 3). Numbers are given for levels of current defoliation, previous damage, tree vigor, and egg-mass population; each number is added to give a hazard rating for that particular sampling location. Depending upon the total, the hazard may be very low, low, moderate, high, or very high (Table 4). Only those areas receiving a 12 or higher are considered for spray recommendation.

Table 3. Spruce budworm hazard rating system from the Maine Forestry Department, Entomology Division

Category	Hazard value
Current defoliation	
Trace	0
Light	1
Moderate	2
Heavy	3
Severe	4
Previous damage	
Trace	0
Light	3
Moderate	6
Severe	9
Dead tops	12
Dead trees	15
Tree vigor	
Poor	+1
Fair	0
Good	-1
Egg-mass populations	
None (0)	0
Light (1 - 100)	1
Moderate (101 - 240)	2
High (241 - 400)	3
Very high (400+)	4

Table 4. Sample point hazard rating categories from the Maine Forestry Department, Entomology Division

Hazard rating	Range of total values
Very low	0 - 4
Low	5 - 7
Moderate	8 - 11
High (spray recommended)	12 - 16
Very high (presalvage)	17 - 24

In September, observers fly a second time over the entire spruce-fir area, this time mapping tree damage. Following these flights, maps are prepared containing hazard rating numbers penciled at the sampling locations. Using this hazard map and the two aerial survey maps, entomologists then delimit areas recommended for a suppression program. During the winter months, additional branch samples containing overwintering larvae are collected and the larvae are counted to assist in designating spray boundaries.

Thus, the procedure for making spray recommendations is a tedious and costly process, using information on both stand condition and insect population levels.

Female Moth Dispersal

Now I would like to discuss the process of female moth dispersal and biology and relate this to the evaluation and decision-making procedure.

The flight behavior of female spruce budworm moths functions to disperse the population by wind (Greenbank, 1973). Females, after depositing part of their egg complement, respond to changing light intensity by flying steeply upward from the stand until they enter the windstream where they are held aloft, thus dispersing from the area (Greenbank, 1973). Depending upon windspeed and the length of time a moth remains in flight, a single female may be carried from 30 to 70 miles on any given night, and she may fly on more than one night (Greenbank, 1973). The factors triggering dispersal are not totally understood, although it is suspected that before dispersing, a female will have deposited a portion of her egg complement (Greenbank, 1973; Leonard,[1] personal communication). Light intensity is apparently an important environmental variable associated with exodus flights

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(Greenbank, 1973), and the flights may be slightly modified by other weather factors (Simmons, unpublished data).

Because the female moth exhibits behavior adapted for wind dispersal, prefrontal thunderstorms can engulf and carry massive numbers of the insect (Greenbank, 1973). Invasions of moths have been observed with the passage of cold fronts (Henson, 1951). For example, flight traps during a normal evening show nil activity by midnight (Figure 1a); while on an evening during a passing cold front, large numbers of moths are captured with the passage of the frontal system (Figure 1b) (Simmons, unpublished data). It is from invasions like these that we observe unusual numbers of moths. Although females carry less than a full complement of eggs (Greenbank, 1973), many egg masses can still be deposited. For example, even though larval populations were reduced to a fraction of an insect per branch through application of insecticides, egg masses averaged over 650 per 100 square feet of foliage this year in eastern Maine (Trial,[2] personal communication). This classified the area at an extreme infestation level. In other areas of the State, egg masses had averaged less than 400 per 100 square feet of foliage in past years. This year the average jumped to nearly 2,000 masses per 100 square feet, with some samples showing as high as 5,000 per 100 square feet of foliage (Stark,[3] personal communication). It is thought that massive moth flights helped account for such high numbers of egg masses both in the unsprayed spruce-fir region and in areas sprayed this past summer. This is a new problem and it raises questions in at least two areas—evaluation of the problem and the choice of control measures.

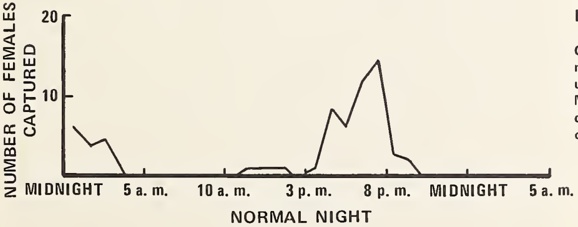

FIGURE 1a.

Captures of female spruce budworm moths in a Malaise trap placed in the upper crowns of balsam fir, Shin Pond, Maine, July 1974. Compare numbers captured between 8 p.m. and midnight on a normal night.

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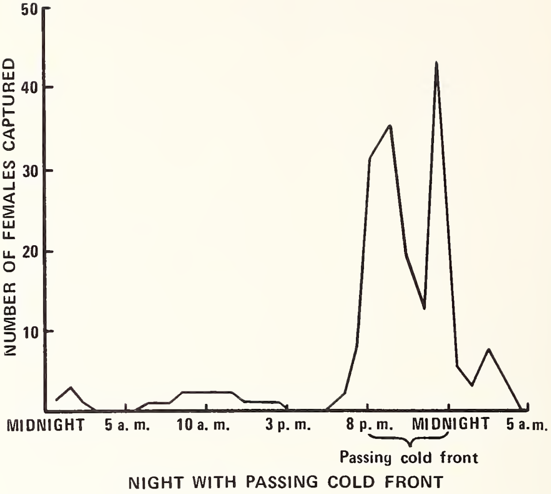

FIGURE 1b.

Captures of female spruce budworm moths in a Malaise trap placed in the upper crowns of balsam fir, Shin Pond, Maine, July 1974. Compare numbers captured between 8 p.m. and midnight on a night with a passing cold front.

Influence on Control Recommendations

Keeping in mind that 400 or more egg masses per 100 square feet of foliage is classed as a severe infestation, densities like 1,000, 2,000, and 5,000 are so high that expected damage cannot be predicted accurately. Should these larger numbers receive more weight in the hazard appraisal? What levels of damage are to be expected with such high numbers? How much tree mortality do we expect? Should previously uninfested areas exhibiting high egg-mass counts be included in next year's spray area? These are all questions which cannot be adequately answered at this time.

With regard to control measures, Maine follows the philosophy of suppression to keep foliage green and trees alive. Populations of the insect, however, are reduced far below what is needed for foliage protection. In most control operations efficacy values are above 85-percent mortality and the number of remaining live budworms average less that one per 18-inch branch. In the past, when infestations were localized, this led toward population suppression with minimal respraying in successive years. Today, however, the Maine infestation is but a portion of a nearly 100-million-acre regional outbreak. Because sprayed lands are subject to moth invasions from adjacent areas, respraying in successive years seems a very real prospect. In view of this, a logical decision is to reduce the amount of pesticide applied per unit area, still achieving adequate foliage protection but allowing larger residual populations of spruce budworm. Lower volume applications could be an important consideration, particularly now, when pesticides are expensive and in limited supply.

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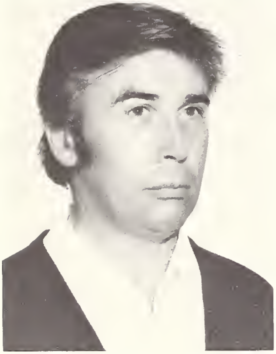
spruce budworm moth dispersal studies (radar)



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presented by E. G. KETTELA

In order to understand how moth dispersal affects population change and redistribution, the Maritimes Forest Research Centre in 1973 employed ground-based radar to measure aerial densities of budworm moths and a DC-3 installed with Doppler wind-finding equipment to study wind fields over New Brunswick. In 1973 this provided evidence of the regular occurrence of budworm moths at high densities in the airspace for several hours each night. Radar showed that the moths were not uniformily distributed in the airspace but tended to band at altitudes corresponding to the top of the temperature inversion. On one night the vast majority of moths would disperse at an altitude of 800 to 900 feet and on the next night at an altitude of 400 to 500 feet. The moths on the average were displaced some 50 to 60 miles in a night.

In 1974 the same equipment showed clearly that dispersing populations are readily concentrated in the airspace by convergent wind fields, and that mass invasions can and do occur in New Brunswick under both convective and stable weather systems. Also in 1974 it became evident that the proportion of a population involved in the dispersal process was determined by weather conditions. Dry, clear airmasses tend to promote long-range dispersal while humid, overcast weather conditions dampen local flight activity and long-range dispersal. Thus, the same weather conditions that favor larval survival also favor long-range moth dispersal.

The logical extension of this research program is to determine whether the aggregation of moths in the airspace is of sufficient density to warrant their consideration as aerial spray targets, and to determine the proportion of the dispersing moth population that would have to be destroyed to significantly affect year to year changes in New Brunswick populations.

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experimental spraying

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Spraying Adult Budworms

The Maritimes Forest Research Centre carried out a moth spray program on approximately 2 million acres (40- by 80-mile rectangle) in northeastern New Brunswick in 1974. The area was divided into 43 spray blocks; TBM's were used to treat 32 blocks, and a DC-6 for the remainder. All but two blocks were treated twice with 1 oz. of phosphamidon; the two exceptions were treated three times.

There were two major problems in spray application: (1) because of retarded budworm development in 1974, the first spray was not applied until July 13, about 1 week later than expected, and (2) due to topographical variations there was a 12-day difference in adult emergence between the "warmest" and "coldest" plots within the spray area. Because of these conditions spraying may have been too early in some blocks to hit the bulk of the female population.

Treatment effects were evaluated from counts of living males in two types of traps, dead adults in collecting trays and mats, and living adults at observation towers. Adult abundance was also checked by on-site radar. Finally, egg counts were obtained on many plots within and outside the spray area.

Analysis of counts of living males in treated versus check plots indicated that over 80 percent of the males were killed within the spray area.

Counts of dead adults in trays and on large mats suggested a high rate of kill (over 70 percent). Male and female mortalities were about equal. However, because we lacked good information on the natural rate of death, we were unable to define the rate of adult mortality caused solely by the treatment.

A broad-scale egg survey suggested there were 38 percent fewer eggs in the TBM-sprayed area and 29 percent fewer in the DC-6 area than in the check plots. By comparison, the most effective adult treatment in 1973 resulted in 56 percent fewer eggs, while in 1972 egg density was reduced by about 40 percent over an 8,000-acre block. Although the application rate was heavier in 1972 and 1973 (2 oz. applied twice), current data indicate a 40- to 50-percent reduction in egg density as a result of the present type of adult spray program. With the 1974 program, we are awaiting radar observations to determine whether the egg masses in the treated area resulted from failure to kill resident females before oviposition, or from invasion, or from both.

Insect Growth Regulators

The Maritimes Forest Research Centre and Ciba-Geigy Canada Ltd. participated jointly in an experiment to further evaluate the insect growth regulator CGA-13353, a Ciba-Geigy product. Six 100-acre spray blocks and one control area were established in the Acadia Forest Experiment Station. Three dosage rates, 1.5, 3.0, and 6.0 oz. per acre, and two applications, one during the fourth instar and the other during the peak of the sixth instar, were tested. Each spray block was treated once. The spray emulsion was applied at the rate of 0.5 gallon per acre with a Cessna Ag-wagon aircraft.

Preliminary analysis of the data indicates that up to 30 percent of the population was affected to the pupal stage. However, there appears to be no discernable response to dosage, mortality, or time of application. Studies by Dr. Outram of "bonus" effects of this compound revealed that it does affect budworm emergence, fecundity, and behavior. He has demonstrated a clear dosage response in the early application series. The maximum effect was in the 6.0 oz. per acre block, where 82.7 percent of the insects reared had some physiological malfunctions. Results of the late series of sprays, however, did not show this dosage response, and this may be due to forest cover type and spray deposit. These trials indicate that CGA-13353 does have a measurable effect on budworm survival and fecundity.

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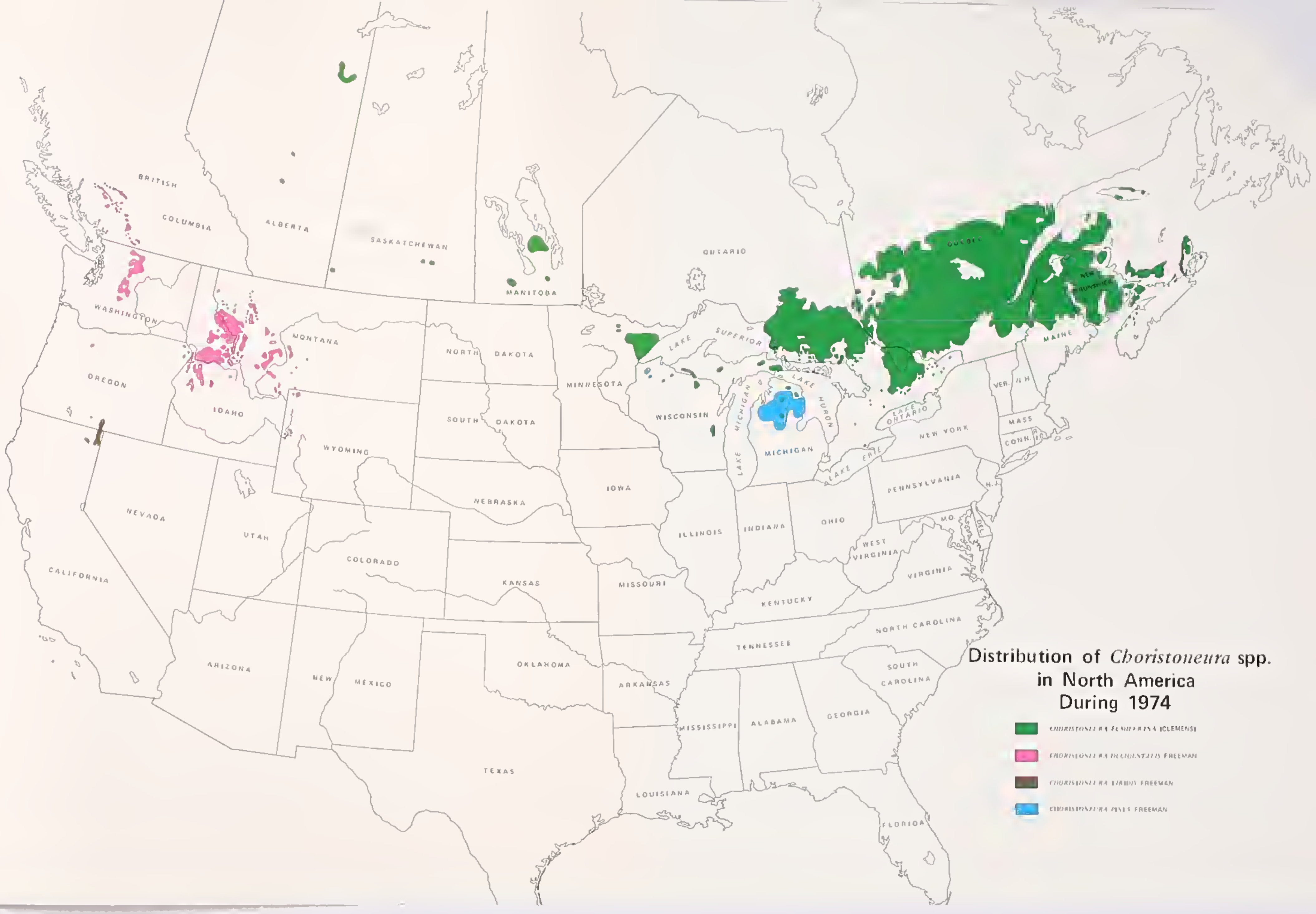
Distribution of *Choristoneura* spp. in North America During 1974

🟩 *CHORISTONEURA FUMIFERANA* (CLEMENS)

🟪 *CHORISTONEURA OCCIDENTALIS* FREEMAN

🟫 *CHORISTONEURA VIRIDIS* FREEMAN

🟦 *CHORISTONEURA PINUS* FREEMAN



Distribution of *Choristoneura* spp. in North America During 1974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